THE ANIMAL

AS A

The Publishers and the Author will be grateful to any of the readers of this volume who will kindly call their attention to any errors of omission or of commission that they may find therein. It is intended to make our publications standard works of study and reference, and, to that end, the greatest accuracy is sought. It rarely happens that the early editions of works of any size are free from errors; but it is the endeavor of the Publishers to see them removed immediately upon being discovered, and it is therefore desired that the Author may be aided in his task of revision, from time to time, by the kindly criticism of his readers.

JOHN WILEY & SONS.

53 EAST TENTH STREET.

NEW YORK:
JOHN WILEY & SONS,
53 EAST TENTH STREET.
1894.

THE ANIMAL

AS A

MACHINE AND A PRIME MOTOR,

AND THE LAWS OF ENERGETICS.

obert enry BY

R. H. THURSTON.

FIRST EDITION.

FIRST THOUSAND.

NEW YORK:

JOHN WILEY & SONS,

53 EAST TENTH STREET.

1894.

CONTENTS.

I. INTRODUCTION.

II. THE ANIMAL AS A PRIME MOTOR.

THE ANIMAL

AS A

MACHINE AND A PRIME MOTOR.

I.

INTRODUCTION.

ENERGY AND ITS TRANSFORMATIONS.

ENERGETICS AND ITS LAWS.

1. **Energy and its Transformations** are the source and the method of all useful work, as of all natural phenomena involving motions of masses or of molecules of whatever kind. All "prime movers" are machines by means of which man diverts energy from natural channels and compels it to do his own work. The water-wheels and windmills simply transfer the energy of the moving fluid to the machinery of the transmission through which it performs useful work; the heat-engines and electric machinery transfer energy, and at the same time convert it from the thermal or the electrical to the dynamic form for application, and thermodynamic or electro-dynamic apparatus thus have two distinct functions.

In some instances we may observe a succession of

transformations of energy, as where a steam boiler transforms, and stores for transmission to the engine, energy of chemical affinity; the engine, in turn, transforming it into mechanical energy and transmitting it to a dynamo-electric machine, where it is again transformed, changing into the electrical current, to be sent perhaps miles away to an electro-dynamic machine or motor, where its retransformation into mechanical power occurs, and it is set at the work of driving a mill or other collection of mechanisms. A telephone system illustrates in another way similar transformations and retransformations of mechanical and electric energy, and Mr. Hammer has thus produced a system involving many transformations and including a circuit of a hundred miles.

Nature herself has in these cases usually already performed some such transformations of energy in the reduction of that so collected and applied to the form in which the mechanic and the engineer finds it ready to his hand. The water has been raised from the lakes and the sea, and distributed by the clouds to the elevated sources from which it flows downward in the streams; the winds are the result of differences of temperature and the action of heat energy; the heat of combustion is the representative of an earlier form of energy in which the heat of the sun and of the still cooling earth, and the formation of the coal deposits in early geological periods, played a part. In a general way it has come to be seen that every display of energy, like every new form of matter, is the result of change in some antecedent form, and that neither matter nor energy can be destroyed. This has been admitted from the time of Lavoisier, so far as it affects matter; it has

been admitted as applicable to physical energy since the doctrines of the correlation of forces and the persistence of energy became accepted by men of science; and we are gradually progressing towards the establishment of a law of persistence of all existence, whether of matter, of force and energy, or of organic vitality, and perhaps even to its extension until it includes intellectual and soul life.

We see that in the beginning there entered upon an existence of indefinite duration a great universe of matter endowed with its characterizing attributes—the forces. These forces, acting upon a definite quantity of matter with definite intensity, give origin to a fixed amount of actual energy, and become capable of producing another fixed quantity of what is now potential energy. Energy thus brought into existence remains constant in total amount as the quantity of created matter remains constant.

The action of these forces upon this matter has given rise to every phenomenon which has come, or which can come, within the range of scientific inquiry.

2. **Forces are Classified,** according to their methods of affecting matter, into three great classes:

(1) Those forces with which we are able to make ourselves so readily and thoroughly familiar that we find no difficulty in assigning to each of them its proper place in the scheme of scientific systematization, and which we have found it comparatively easy to distinguish by their peculiar and readily observed effects. These include the familiar physical forces, as gravitation, electrical, chemical, and mechanical forces.

(2) The vital forces—those which are preservative of all life, which produce and promote the growth of or-

ganisms having life, and which are less easily understood, more difficult to study, and far less subject to the modifying power of human action, than are those of the first described class.

(3) The forces of the soul and of the intellect—those most wonderful and most mysterious of all known forms of force—forces of the nature of which we know nothing, and of the effects of which, actual and possible, we have the least comprehension.

By the study of the universe as it now exists, philosophers are led to perceive that its present state is such as would have resulted had the various forms of matter with which we are surrounded, and of which we ourselves are corporeally formed, and had other existences which we suppose to form a part of our universe been, at the beginning, so distributed and so placed in reference to the several kinds of forces that the former, acted freely upon by the latter, should, by a continuity of never-ceasing, ever-progressing change, take those infinite variations of growth, and all that inconceivable variety of shapes, that have supposed to have been, by the process called "evolution," brought into the visible universe.*

Studying the accessible universe, as far as we are permitted, in greater detail, we find that each of the various kinds of forces set at work to modify the position and character of matter has a special part to play, a peculiar work to do; we find that the first class has a

* As early as 1854 Helmholtz showed that the condensation of an infinitely diffused nebulous mass of matter, to form the stellar systems of the universe, by gravitation, was sufficient to furnish all existing heat-energy, and a source of all that mechanical and other transformed energy known now to exist.

sphere of operation which is fully within the reach of our senses; that the second class of forces is also, to a certain extent, familiar to us through a knowledge of their effects: but the last of these several classes of forces existing in nature is, as yet, quite beyond our ken.

Studying these forms of manifestation of force which are divided between the first two classes, we perceive a distinction which is as well defined as is the line separating the two classes of phenomena to which they give rise.

(1) The *physical forces*—and it is intended here to include the mechanical and chemical, as well as the forces which are usually alone treated of in works on physics—are capable of being observed, of being distinguished by certain readily defined qualities, and of being accurately measured quantitatively. The conditions which lead to their active display are capable of being exactly ascertained, and the precise results of their operations under any given set of conditions may usually be accurately predicted. These conditions are subject to certain definite modifications by the power of man, and the changes of effect which will result from such changes of condition may be predicted. The effects which nature produces in certain cases by the action of these forces may be modified by man without entirely defeating the original tendency to bring about a certain change of mode of action of existing energy. These forces, acting alone, never give rise to the more intricate forms seen in nature. Their highest product in the whole morphological range is a crystal of more or less perfect shape, but of a form which is always of some simple geometrical class. These forces do not

exhibit the play of definitely directed energy tending to effect a perfectly well defined, though remote, result. Their effects are the accidental and the incidental, so far as the more wonderful and most intricate of the operations of nature are concerned.

(2) The *vital forces*, on the other hand, effect operations which human power can only touch to impede or to destroy. They have for their mission the creation of strangely complicated and curiously organized structures, in which are stored certain definite amounts of energy, and which are given a power of acquiring and of applying extraneous energy, in probably also definite amount, to the accomplishment of certain tasks. Man may modify their operation and may produce some change in the phenomena which they are appointed to bring about; but it is only by deranging their action. He can mar their work, but cannot directly aid them. That store of vital energy which was created in the infinite past, and which is now passing through one after another of the forms of life, new and old, which are constantly coming into the field of our cognizance, and as constantly disappearing from view, is continually developing organisms of every grade from the simple life-seed, if such exist—from the basic protoplasm—to the human ruler of them all.

Of these two sets of forces, the one is blind and aimless, unintelligent as to the direction of its efforts, indifferent as to its results, and is governed by laws which, under all known conditions, are as simple as they are invariable. The other set appears to act at all times upon a definite, far-reaching plan, and these forces set themselves intelligently about the production of the most elegant and intricate of designs, and the

elaboration of the most wonderful and mysterious of organisms. It is only in the structures which are their work that the strange, the incomprehensible phenomena of life are exhibited to the intelligence which vainly endeavors to understand them.*

3. **Energy,** "living Force," ever-living force, as we are now learning to regard it; *vis viva,* as its first discoverer, Leibnitz, called it; the force illustrated in all life and motion, as we now know it; *energy,* as Dr. Young first denominated it: all these expressions for one common quality of every body, substance, or system, in motion either as to its atoms or molecules or as to its mass, denote that mysterious property by which all growth, all life, all changes in physical things or physical substance are brought about and continued. The work of the vegetable kingdom, in the elevation of the simpler, inorganic compositions found in nature to the higher, complex, organic forms in which they find their culmination; those of the animal system which take these complex forms and erect them in a still more complicated animal structure and supply it with the powers of animal life; the work of the living creature in again reducing these complicated structures to the lower and simplest forms, availing itself of their latent energy in the production of all the grandest results of physical and intellectual life: all these are but manifestations in various ways of the ever-living forces, the never-ceasing energies, of the universe.

In its two forms, kinetic and potential, actual and

---

* The preceding matter is from the vice-president's address before the American Association for the Advancement of Science, R. H. Thurston, 1878.

latent, the sum of which is constant throughout the universe, energy is the source and the basis of all life, of all motion, of all development, of all evolution. It is the mainspring of all physical phenomena; and the science of *Energetics* is the foundation of chemistry, as of physics; of astronomy, as of the mechanics of engineering. Whatever we know of matter, even, is discovered to us by these methods of display of energy in connection with it.

The science of energetics itself is one division of a broader science, that of *Mechanics*,—that great science which bears more or less directly upon every phenomenon of nature and the universe, and which is at the foundation of all the applied sciences, of all the arts of construction, of all the exact sciences of physics and chemistry, of astronomy, and of forces and motions.

4. **Mechanics** thus includes four principal divisions:*

(1) *Statics* treats of the relations of forces acting in any system when no motion results from that action.

(2) *Kinematics* treats of the relations of motions simply, of their composition and resolution, and of their resultant effects.

(3) *Dynamics* or *Kinetics* treats of the motions produced in ponderable bodies by the action of forces.

(4) *Energetics* treats of the measurement, the transfer, and the transformations of energy under the action of forces, and of their result in the variation of the method of its manifestation.

5. **Energetics is defined,** therefore, as that science which treats of all natural phenomena which, through

* Several pages are here taken mainly from "The Manual of the Steam Engine," vol. 1, by R. H. Thurston; N. Y., J. Wiley & Sons.

the action of force upon matter, result in the production of motion; whether it be a relative motion of atoms, of molecules, or of masses. It is that science "whose subjects are material bodies and physical phenomena." * We may here repeat:

Energetics thus treats of modifications of energy under the action of forces, and of its transformation from one mode of manifestation to another, and from one body to another; and within this broader science is comprehended that latest of the minor sciences—of which the heat-engines and especially the steam-engine illustrate the most important applications—*Thermodynamics.* The science of energetics is simply a wider generalization of principles which have been established one at a time, and by philosophers widely separated, both geographically and historically, by both space and time, and which have been slowly aggregated, to form one after another of the physical sciences, and out of which we are slowly evolving wider generalizations; thus tending toward a condition of scientific knowledge which renders more and more probable the truth of a principle, still broader than this science, even, and which was enunciated before Science had a birthplace or a name; i.e.:

All that exists, whether matter or force, and in whatever form, is indestructible by any finite power.

As already remarked, that matter is indestructible by finite power became admitted as soon as the chemists, led by Lavoisier, began to apply the balance, and were thus able to show that in all chemical change there occurs only a modification of form or of combination

---

* Rankine; Proc. Phil. Soc. Glasgow; vol. III. No. 6.

of elements, and no loss of matter ever takes place. The "persistence" of energy was a later discovery, consequent largely upon the experimental determination of the convertibility of heat-energy into other forms and into mechanical work, for which we are indebted to Rumford and Davy, and to the determination of the quantivalence anticipated by Newton, shown and computed approximately by Colding and Mayer, measured with great accuracy by Joule and Rowland.

It is now generally understood that all forms of energy are mutually convertible with a definite quantivalence; and it is not certain that even vital and mental energy do not fall within the same category.

The essentially important, as well as interesting, fact, in this connection, to the engineer as well as to the physicist, it should be noted, is that the laws of energetics apply unqualifiedly to atomic and molecular phenomena, as well as to energies of masses, and to all transformations of energy in either class and of any kind. There is, dynamically, absolutely no distinction, in this respect, between the methods and processes of chemistry, of physics, and of the mechanics of masses. All illustrate phases of one science, and all are energies of matter in motion.

6. **Matter, Force, and Energy** are the only quantities known to the departments of natural science. The science of *Chemistry* deals with the forms which matter assumes under the action of measurable atomic molecular forces affecting dissimilar kinds of matter; *Physics* is that science which deals with all the other forms of sensible force and their effects. The science of *Energetics* treats of the action of forces producing

or modifying energy, whatever the kind of force, whatever the kind of matter: it thus covers the whole range of chemistry and physics.

Matter is that which is capable of directly affecting the senses, and which occupies space. Nothing is known of the ultimate nature of matter, and we are acquainted with it only as it affects the organs of the body. It is usually divided into four classes: solids, liquids, gases, and imponderable matter; the latter meaning that which cannot be assigned a finite specific measure of mass or weight. The luminiferous ether is an example of this last; the other three are familiar forms.

A *Body* is a limited portion of matter.

Force is that which produces, or tends to produce, motion, or change of motion, in bodies; it is measured statically by the weight which will counterpoise it or by comparison with a known standard of force, and dynamically by the velocity which it will give a known freely moving mass in a stated time, i.e., by the "acceleration" which it is capable of producing.

Work is always performed by the expenditure of energy, and is the product of the resistance overcome by a force, or of the effort exerted by it, into the space through which that action takes place. That resistance may be constant, or variable, and due to an active, opposing force, to resisting pressure, to the inertia of masses, or of molecules compelled to submit to acceleration or retardation; or it may be due to any one of the physical or chemical forces. Thus, if U represents the work done by a force, F, acting through a space, s,

$$U = Fs = Rs; \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and for motion variable only,

$$dU = Fds. \qquad \qquad (2)$$

For variable forces,

$$dU = sdF. \qquad \qquad (3)$$

For forces and motion variable,

$$dU = d(Fs) \qquad \qquad (4)$$

The Unit of Work is the product of the units of its factors force and space, as the foot-pound, the kilogrammetre, the foot-ton, the gramme-centimetre.

Useful Work is that which is applied to the production of a specified useful effect; *Lost Work* is that which is incidentally wasted, in the endeavor to perform useful work, in overcoming prejudicial resistances, and in doing useless work; this waste occurs usually and principally in overcoming friction of moving parts.

Work of Acceleration is work expended in producing increased velocity in a freely moving body. The effort exerted, and the resistance met, is dependent upon the inertia of the mass, and is measured thus: A body moving freely under the action of gravity, i. e., of a force equal to its own weight, acquires, in this latitude, a velocity of 32.2 feet (9.81 metres), nearly, in one second, and the acceleration, or retardation, of any freely-moving body is proportional to the effort applied, as to the resistance met by it. If f is the actual acceleration, if g measures that produced by gravity, if F is

the statical measure of the effort, and W is the weight of the body, we have

$$F : W :: f : g; \quad t : 1 :: v_2 - v_1 : f;$$

$$F = \frac{f}{g} W;$$

$$= \frac{v_2 - v_1}{gt} W; \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

v_1 and v_2 being the initial and final velocities, and t the time of action of the accelerating force.

For variable acceleration,

$$f = \frac{dv}{dt}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$F = \frac{dv}{dt} \cdot \frac{W}{g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The space, s, is equal to $\frac{v_2 + v_1}{2} t$, and the *work* done is, for uniform acceleration,

$$U = Fs = \frac{v_2 - v_1}{t} \cdot \frac{v_2 + v_1}{2} \cdot t \cdot \frac{W}{g}$$

$$= W \frac{v_2^2 - v_1^2}{2g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

For variable acceleration,

$$U = d\,(Fs) = W . d . \frac{v^2}{2g} = W \frac{vdv}{g}. \quad . \quad . \quad (9)$$

Since $\frac{v_2}{2g} = h$, the height due the velocity v, the work is equal to that required to raise the body through the difference of the two heights due the initial and the final velocities, respectively.

Where the motion of the machine or of the part doing work is circular, the space traversed may be measured by the angular motion a, multiplied by the lever-arm, l, and their product, multiplied by the force, R, exerted, gives the measure of the work done. Thus:

$$\left.\begin{aligned} U &= aRl \\ &= 2\pi nRl; \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

in which last expression n is the number of revolutions made in the unit of time.

These values are equivalent to the product of the angular motion into the moment of the resistance.

Work may also be measured, as in steam, air, gas, or water pressure engines, by the product of the area of piston, A, the mean intensity of pressure upon it, p, the length of stroke of piston, l, and the number of strokes made. Thus,

$$\begin{aligned} U &= Apln \\ &= Aps \\ &= pV, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11) \end{aligned}$$

when V is the volume of the working cylinder multiplied by the number of strokes; in other words, the volume traversed by the piston.

Where the force acting, or the resistance, acts obliquely to the path traversed, it is evident that only the component in that path is to be considered.

Diagrams exhibiting the amount of work done and

the method of its variation are often found useful. In such diagrams the ordinate is usually made proportional to the force acting, or to the resistance, while the abscissas are made to measure the space traversed. The curve then exhibits the relations of these two quantities, and the enclosed area is a measure of the work performed. With a constant resistance, the figure is rectilinear and a parallelogram; with variable velocities and resistances, it has a form characteristic of the methods of operation of the part or of the machine the action of which it illustrates.

Power is defined as the *rate of work*, and is measured by the quantity of work performed in the unit of time, as in foot-pounds or in kilogrammetres, per minute or per second. The unit commonly employed by engineers is the "horse-power," which was defined by Watt as 33,000 foot-pounds per minute, equivalent to 550 per second, or 1,980,000 foot-pounds per hour. This is considered to be very nearly the amount of work performed by the very heavy draught-horses of Great Britain; but it considerably exceeds the power of the average dray-horse of that and other countries, for which 25,000 foot-pounds may be taken as a good average amount.

The metric horse-power, called by the French the *cheval-vapeur*, or *force de cheval*, is about 1½ per cent. less than the British, being 542.47 foot-pounds or 75 kilogrammetres per second, 4500 kilogrammetres per minute, or 270,000 per hour. These quantities are almost invariably employed to measure the power expended and work done by machines.*

* Various nations have a standard "horse-power" derived from Watt's, but, owing to differences in weights and measures, they are not

It is evident that power is also measured by the product of the resistance, or of the effort exerted into the velocity of the motion with which that resistance is overcome or that force exerted. Since $s = vt$,

$$U = Rs = Rvt;$$

and when t becomes unity, the measure of the power, or of the equivalent work done in the unit of time, is

$$U' = Rv,$$

in which the terms are given in units of force and space as above.

The power of a prime mover is usually ascertained by experimentally determining the work done in a given time, the trial usually extending over some hours, and often several days. It is measured in foot-pounds or

---

identical; but the differences are usually less than 1½ per cent. The following table, compiled by Mr. Babcock, gives these standards in kilogrammetres per second, and in foot-pounds per second expressed in the foot and pound standards of each country.

STANDARD HORSE-POWER FOR DIFFERENT NATIONS.

COUNTRY.	Kilogram-metres per second.	Baden ft.-pounds per second.	Saxon ft.-pounds per second.	Wurtem-berg ft.-pounds per second.	Prussian ft.-pounds per second.	Hanoverian ft.-pounds per second.	English ft.-pounds per second.	Austrian ft.-pounds per second.
France and Baden	75	500	529.68	521.58	477.93	513.53	542.47	423.6
Saxony........	75.045	500.30	530	523.89	478.22	513.84	542.80	423.9
Wurtemberg	75.240	501.36	531.12	525	479.23	514.92	543.95	424.8
Prussia........	75.325	502.17	531.97	525.85	480	515.75	544.82	425.5
Hanover..........	75.361	502.41	532.23	526.10	480.23	516	545.08	425.7
England....	76.041	506.94	537.03	530.84	484.56	520.65	550	429.5
Austria	76.119	507.46	537.58	531.39	485.06	521.19	550.57	430

kilogrammetres: the total work so measured is then divided by the time of operation and by the value of the horse-power for the assumed unit of time and the mean value of the power expended thus finally expressed in horse-powers.*

The forces acting in machines are distinguished into *driving* and *resisting forces.* That component of the force, acting to produce motion in any part which lies in the line of motion only, is that which does the work; and this component is distinctly called the "Effort." Similarly, only that component of the resistance which lies in the line of motion is considered in measuring the work of resistance. In either case, if the angle formed between the directions of the motion of the piece and of the driving or the resisting force be called α, the effort is

$$P = R \cos \alpha, \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The other component, acting at right angles to the path of the effort, is

$$Q = R \sin \alpha, \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and has no useful effect, but produces waste of power by introducing lateral pressures and consequent friction.

Energy, which is defined as capacity for performing work, is either *actual* or *potential.*

Actual or *Kinetic Energy* is the energy of an actually moving body, and is measured by the work which it is capable of performing while being brought to rest, under the action of a retarding force; this work is

* Custom has not yet settled the proper form of the plural of this word; there is no reason why it should not follow the rule.

equal to the product of its weight, W, into the height, $h = \frac{v^2}{2g}$, through which it must fall under the action of gravity to acquire that velocity, v, with which it is at the instant moving; i.e.,

$$E = U = Wh = W\frac{v^2}{2g}. \quad . \quad . \quad . \quad (14)$$

A change of velocity v_1 to v_2 causes a variation of actual energy, $E_1 - E_2$, and can be effected only by the expenditure of an equal amount of work—

$$E_1 - E_2 = U = W\frac{v_1^2 - v_2^2}{2g} = W(h_1 - h_2). \quad (15)$$

This form of energy appears in every moving part of every machine, and its variations often seriously affect the working of mechanism.

The total actual energy of any system is the algebraic sum of the energies, at the instant, of all its parts; i.e.,

$$E = \Sigma W\frac{v^2}{2g}; \quad . \quad . \quad . \quad . \quad . \quad (16)$$

and when this energy is all reckoned as acquired or expended at any one point, as at the driving-point, the several parts having velocities, each n times that of the driving-point, which latter velocity is then v, the total energy becomes

$$E = \Sigma W\frac{n^2v^2}{2g}. \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Actual energy is usually reckoned relatively to the earth; but it must often be reckoned relatively to a

given moving mass, in which case it measures the work which the moving body is capable of doing upon that mass, when brought by it to its own speed.

Potential Energy is the capacity for doing work possessed by a body in virtue of its position, of its condition, or of its intrinsic properties. Thus, a weight suspended at a given height possesses the potential energy, in consequence of its position, $E = Wh$, and may do work to that amount while descending through the height, h, under the action of gravity. A bent bow or coiled spring has potential energy, which becomes actual in the impulsion of the arrow or is expended in the work of the mechanism driven by the spring. A mass of gunpowder or other explosive has potential energy in virtue of the unstable equilibrium of the chemical forces affecting its molecules. Food has potential energy in proportion to the amount of vital and muscular energy derivable by its consumption and utilization in the human or animal system. These potential energies are not measured by the observed actual energies derived from these substances in any case, but are the maximum quantities possibly obtainable by any perfect system of development and utilization. In practical application, more or less waste is always to be anticipated.

Every instance of disappearance of actual energy involves the performance of work, and the production of potential or of some new form of actual energy in precisely equal amount. A stone thrown vertically upward loses kinetic energy as it rises, in precisely the amount—resistance of the air being neglected—by which it gains potential energy. A falling mass striking the earth surrenders the actual energy acquired by loss

of potential energy during its fall, and the equivalent of the quantity so surrendered is found in the work done upon the soil; it finally passes away as the equivalent energy of heat motion produced by friction and impact. The potential chemical energy of the explosive is the equivalent of the kinetic energy of the flying projectile, and the latter has its equivalent in the work done at the instant of striking and coming to rest, and in the heat produced by the final change of mass-motion into molecular or heat motion.

Work may be defined as that operation which results in a change in the method of manifestation of energy, and Energy as that which is transferred or transformed, when work is done. The motion of a projectile is the transfer of energy from one place to another. It is generated at the point of departure, stored as actual or kinetic energy, transferred to the point of destination, and there restored and applied to the production of work.

Acceleration and retardation of masses in motion can only be produced by doing work upon them, or by causing them to do work, and thus, by the communication of energy to them or by its absorption from them, in precisely the amount which measures the variation of their actual energy as so produced. Every body which is increasing in velocity of motion thus receives and stores energy; every mass undergoing retardation must perform work, and thus must restore energy previously communicated to it. In every machine which works continuously, and in which parts are alternately accelerated and retarded, energy is stored at one period and restored at another, in precisely equal amounts.

Work done upon any machine may thus be expended

partly in doing the useful work of the system, and partly in storing energy; and the same machine may do work at another instant partly by expending the energy received by it, and partly by expending stored energy previously accumulated.

Storage or restoration of energy thus always occurs when change of speed takes place. It is evident, since the storage or restoration of energy implies variation of speed, that the condition of uniform speed is that the work done upon the machine shall at each instant be precisely equal to that done by it upon other bodies, The work applied must be equal to that of resistance met at the driving-point. Thus,

$$\Sigma Pv - \Sigma Rv'; \int Pdv = \int Rdv'; \quad . \quad . \quad (18)$$

and the effort at each point in the machine will be equal to the resistance, and will vary inversely as the velocity of the point to which it is applied; i.e.,

$$\frac{P}{P'} = \frac{v'}{v}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

In the starting of every machine, energy is stored during the whole period of acceleration up to maximum speed, and this energy is restored and expended while the machine is coming to rest again. This latter quantity of energy is usually expended in overcoming friction.

The useful and the lost work of a machine are, together, equal to the total amount of energy expended upon the machine, i.e., to the work done upon it by its "driver." The *Useful Work* is that which the machine is designed to perform; the *Lost Work* is that which is

absorbed by the friction and other prejudicial resistances of the mechanism, and which thus wastes energy which might otherwise be usefully applied. These two quantities, together, constitute the *Total Work* or the *Gross Work* of a machine, or of a train of mechanism. In every case some energy is wasted, and the work done by the machine is by that amount less than the work performed in driving it. In badly proportioned machines the lost work is often partly expended in the deformation and destruction of the members of the construction; in well-designed and properly worked machinery loss occurs wholly through friction. In machines acting upon fluids this work is usually partly wasted in the production of fluid friction—i.e., of currents and eddies; thus producing new forms of actual energy in ways which are not advantageous: even this waste energy is finally converted, like the preceding form, by molecular friction, into heat, and is dissipated in that form of molecular energy. Thus all wasted work is lost by conversion from the energy of mass-motion into molecular energy, and ultimately disappears as heat.

The Efficiency of Mechanism is measured by the quantity obtained by dividing the amount of useful work performed, by the gross work of the piece or of the system. It is always, therefore, a fraction, and is less than unity; which latter quantity constitutes a limit which may be approached more and more nearly as the wastes of energy and work are reduced, but can never be quite reached. If the mean useful resistance be R, and the space through which it is overcome be s', and if the mean effort driving the machine be P, and the space through which it acts be s, the total and the *net* or *use-*

ful work will be, respectively, Ps, Rs'; the *lost work* will be $Ps - Rs'$, and the

$$\text{Efficiency} = \frac{Rs'}{Ps} < 1. \quad . \quad . \quad . \quad . \quad (20)$$

Counter-efficiency, C, is the reciprocal of the effiency; i.e.,

$$C = \frac{Ps}{Rs'}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

The efficiency and the counter-efficiency of a machine, or of any train of mechanism, are the products of the efficiencies or of the counter-efficiencies of the several elements constituting the train transmitting energy from the point at which it is received to that at which the work is done, i.e., from the "driving" to the "working" point.

Friction is the principal cause, and usually the only cause, of loss of energy and waste of work in machinery. A given amount of energy being expended upon the driving-point in any machine, that amount will, in accordance with the principle of the persistence of energy, be transmitted from piece to piece, from element to element, of the machine or train of mechanism, without diminution, if no permanent distortion takes place and no friction occurs between the several elements of the train, or between those parts and the frame or adjacent objects. Temporary distortion, within the limit of perfect elasticity, causes no waste of energy; permanent distortion, however, causes a loss of energy equal to the total work performed in producing it. But permanent distortion is due to deficiency of strength and defective elasticity, and is never permitted in well-designed

machinery properly operated; and hence the important principle:

In engineering, the principles of pure mechanism, of theoretical mechanics, and pure theory in the science of energetics, or of thermodynamics, are to be studied as introductory to a science of application in which all actions and all calculations are to be considered with reference to the modifications produced by the wastes of energy and the alteration of the magnitudes and other properties of forces consequent upon the occurrence of friction.

7. **The Laws of Energetics,** the basis of the science which it has been proposed to call by that name, are:

(1) *The Law of Persistence, or of Conservation of Energy:*—Existing energy can never be annihilated; and the total energy, actual and potential, of any isolated system can never change.

This is evidently a corollary of that grander law, asserting the indestructibility of all the work of creation, which has already been enunciated.

(2) *The Law of Dissipation, or of Degradation of Energy:*—All energy tends to diffuse itself throughout space, with a continual loss of intensity, with what seems, now, to be the inevitable result of complete and uniform dispersion throughout the universe, and, consequently, entire loss of availability.

It is only by differences in the intensity of energy, and the consequent tendency to forcible dispersion, that it is possible to make it available in the production of work.

(3) *The Law of Transformation of Energy:*—Energy may be transformed from one condition to another, or from any one kind or state to any other; changing

from mass-energy to molecular energy of any kind, or from one form of molecular energy to another, with a definite quantivalence.

These laws lead to the conclusion that, in any isolated system of bodies, or in any isolated mass, the total of all energy present is always the same; though it may be transformed in various ways, and to an extent only limited by the special conditions affecting the system. They lead to the conclusion that energy of higher intensity than the mean must occupy a limited space, and will continually tend to dissipate itself by dissemination through a greater volume, affecting larger and larger quanties of matter, with proportional reduction of intensity, until the whole system is occupied by the originally existing energy, at a finally uniform and minimum intensity. Energy confined within a limited space thus continually tends to expand, and to break through its boundaries, and, if not freed from this constraint, it produces a pressure upon the surrounding surfaces, which, e.g., is exhibited as tension of enclosed vapors and gases. Freed from confinement, it tends to indefinitely expand.

Either form of energy may produce either other form under suitable conditions.

Rankine's statement of the "General Law of the Transformation of Energy" is as follows: *

"The effect of the whole actual energy present in a substance, in causing transformation of energy, is the sum of the effects of all its parts."

The *axiom*, as Rankine calls it, that "any kind of energy may be made the means of performing any kind

* Proc. Phil. Soc. of Glasgow; vol. III. No. 5; 1853.

of work" is derived by "induction from experiment and observation," and confirmed by all experience.

The Sources of Energy are : (1) Potential : (*a*) fuel ; (*b*) food ; (*c*) head of water ; (*d*) chemical forces. (2) Actual : (*a*) air in motion ; (*b*) gravity in waterfalls ; (*c*) tides.

8. "**Newton's Laws**" follow directly from the general law of persistence of energy, a corollary to which may be stated thus : Change of energy can only be produced by the action of force, and by doing work. *Newton's Laws* are :

(1) A free body tends to continue in the state in which it, at any instant, exists, either of rest or of uniform rectilinear motion.

(2) All change of motion in a body free to move is proportional to the force impressed, and is in the direction of that force.

(3) The reaction of the body acted upon by the impressed force is equal, and directly opposed, to that force.

Inertia is that property, observed in all bodies, in consequence of the existence of which they are capable of exhibiting the action of these laws. The laws of Newton themselves are all easily verified by experiment. The "Atwood Machine," illustrated in nearly all works on physics, is constructed for this special purpose.

While Newton's laws are readily verified by experiment, the more general laws of energetics are accepted simply as being in accordance with universal experience. The generally accepted theory of the constitution of matter being assumed as a premise, however, the general laws of energy are all easily deducible from Newton's laws. Thus, the first law is but a differ-

ently worded statement of Newton's three laws combined.

To assert that every moving body tends to persist in its rate of motion, exerting an effort always equal to the retarding or accelerating force, and exerting such effort in the line of action of such force, is to assert that its energy can only be altered by the performance of an equivalent amount of work, and an equal amount of energy of opposite sign; and this latter assertion is a declaration of the indestructibility of energy. To assert that all bodies, whether masses or molecules, when in motion tend to move in rectilinear paths, is to assert a tendency to unlimited dissipation of energy through space. To assert that all matter in motion is subject to Newton's laws is to assert the laws of universal conservation of energy, and of the quantivalence of all transformations, as stated in the third general law. Whenever it becomes established that any phenomenon, as the transfer of heat, of light, of electricity, or of sound, is a mode of motion affecting bodies of whatever class, Newton's laws bring that phenomenon within the scope of the general laws of energy. Every phenomenon, molecular or other, which involves relative motion of masses, vibrations of parts, or pulsations in fluid media, is now well understood to be subject to these laws.

9. **Algebraic Expressions** of the transformability of the energies are now readily deduced. If in any isolated system a certain quantity of energy exists, homogeneous in character and heterogeneously distributed; and if, by any process, other and various forms of energy appear in that system, these latter must be the result of transformations of parts of the initial stock of energy by conversion into the new

forms. But every such change must be effected by a perfectly definite and exact quantivalence.

Assuming this ratio of values of customary units reduced to a system of equivalents, it becomes at once practicable to measure all these energies in the same units; as, for example, when Joule measures either heat or mechanical energy, taking $J = 778$ foot-pounds, as the equivalent of a British thermal unit, or $J =$ about 427 *kilogrammetres*, as the equivalent of one calorie or metric thermal unit; the thermal unit being defined as the quantity of heat or energy-equivalent demanded to raise the temperature of unit weight of water one degree from the temperature of maximum density.

Taking either kind of unit in thus measuring, we shall have the initial stock of the one kind of energy altered by the quantity which, in the same units, measures the aggregate several quantities of energy resulting from the change; and

$$dE = \frac{dE}{dT}dT + \frac{dE}{dU}dU + \frac{dE}{dV}dV +, \text{etc.}; \quad . \quad (1)$$

where E, T, U, V, etc., are the symbols representing the several energies, initial and other.

If T measure heat-energy, and U be taken as potential energy of the molecular kind, V the potential energy of an elastic fluid varying in volume, W the work of some mechanism or a dynamic process, the total variation of the initial energy E, will be equal to the total of all the new energies and the new work, in proportions which become known as soon as the partial coefficients $\frac{dE}{dT}$, etc., are determined.

If two energies only, as thermal and mechanical, are affected, and if the original stock were simply heat-energy, we should have a change, dE, in the initial stock of heat-energy, which would be the precise equivalent of the sum of the two changes taking place, simultaneously, in the initial store and in the temperature, T, of the system, and in work by the change of volume, V, against a pressure of, say, the intensity p. Then, obviously,

$$dE = \frac{dE}{dT}dT + \frac{dE}{dV}dV; \quad . \quad . \quad . \quad . \quad (1)$$

and, since $\left(\frac{dE}{dT}\right)_v$ measures the specific heat, K_v, for constant volume, and as $\left(\frac{dE}{dV}\right)_T$ must measure the intensity of pressure producing, or resisting, the change of volume,

$$dE = K_v dT + pdV. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If but one kind of transformation occurs, as by conversion of any original form of energy, E, into work, a process illustrated in every purely thermodynamic, thermo-electric, or electro-dynamic operation,

$$dE = pdV; \text{ or, } dE = RdS. \quad . \quad . \quad . \quad (3)$$

Whatever the method of transformation of actual energy, it is simply a process of transfer of the energy of motion from one kind of matter to another, or from a mass to a collection of molecules, with, usually, modification of the mode of motion, as from rectilinear to vibratory, or from motion in an orbit of one form to movement in a path of different character.

10. **The Object of all Mechanism** is to produce a certain definite motion of some part or parts—the position and form and the methods of connection of which are known and fixed—against any resistance that may be met with in the course of such movement. Every machine and every train of mechanism is therefore a contrivance by means of which energy or power available at one point, usually in definite amount and acting in a definite direction and with definite velocity, is transferred to other points, there to do work of definite amount, and there to overcome known resistances with known velocities.

The object of the engineer in designing mechanism is to effect this transfer of energy and these transformations at the least cost and with least "running expense," and hence with maximum efficiency of apparatus. It is often important to secure minimum volume and weight of machine, as well as maximum effectiveness in operation.

The work of a machine is measured by the magnitude of the resistance encountered and the velocity with which it is overcome. The nature of the work, aside from its simple kinetic character, is as widely variable as are the details of human industry.

Prime Movers are those machines which receive energy directly from natural sources, and transmit it to other machines which are fitted for doing the various kinds of useful work. Thus, the steam-engine derives its power from the heat-energy liberated by the combustion of fuel; water-wheels utilize the energy of flowing streams; windmills render available the power of currents of air; the voltaic battery develops the energy of chemical action in its cells; and, through

the movement of electro-dynamic mechanism, this energy is communicated to other machinery, and thus caused to do work.

Machinery of Transmission is used in the transformation of energy supplied by the prime mover into available form, for the performance of special kinds of work, or for simple transmission of power from the prime mover to machines doing that work.

11. The Sources of Energy, applied by man, through the prime movers, to the economic purposes of life, are six in number:

(1) The potential energy of fuel, coming of the storage, in early geological periods, of the actual energy of the heat, light, and chemical forces of the sun's rays, and the energy of the dispersing internal heat of the earth, gathered up by the vegetation, and, in case of the mineral oils, possibly, by the animal life, of those primitive ages, reduced to this potential form and stored in the depths of the earth for use in modern times. Very possibly a still earlier history of this energy may be traced in the gradual transformation of the potential dynamic energy of a chaotic universe, infinitely dispersed, into the heat-energy of collision of particle with particle, and of globe with globe, as the existing systems of worlds took form. The potential energy of fuel is converted by combustion into active form.

(2) The dynamic, the kinetic, energy of falling water, transferred through water-wheels without transformation, to do useful work.

This has a similar origin to the preceding; the water being raised from the seas, lakes, and streams to the clouds by the action of the heat of the sun, thus carried

to the higher portions of the land, again to return in the streams to the sea-level.

(3) The kinetic energy of the air-currents, as utilized by windmills, which convert it to useful purposes precisely as the water-wheel intercepts the energy of falling water with a similar end.

The primary source of this energy is again the heat of the sun, which produces a convection of air-currents similar dynamically, in method and result, to those of water in the ocean or over or on the land.

(4) The energy of the tides, the rise and fall of which constitute a source of power less easy of utilization than that of streams, and for this reason, rarely applied to the production of power.

The origin of this energy is in the force of gravitation as it acts upon the ocean, changing its level through the attractions of the sun and the moon. This is seen to be essentially different from the other cases.

(5) The energy of electricity, originally exhibited either in the form of molecular energy resulting from chemical action, or produced by transformation directly from the dynamic form. In this latter case, the machine transforming it is an intermediate or a secondary, instead of a prime, motor. In the former case the origin is potential, in the latter kinetic.

(6) The energy of muscular action, the power of animals, derived from the chemical forces acting in the production of vegetation and transformed for use in the animal system, through either thermo-electric or thermodynamic processes, or perhaps through the action of both, each having its appropriate task.

In the animal system, the vegetable matter employed as food is converted by the natural forces of digestion

and nutrition into available form for use by the nervous and muscular systems of the body, by means of intermediate processes which are as yet obscure. It is only certain that they cannot all be thermodynamic processes ; it seems probable that they are, in some cases, at least, related to the electrical methods of transformation. In some instances, as in the carnivora, the final conversion results from a double transformation,

Thus substantially all utilized natural energy is derived, directly or indirectly, from the sun.

According to Sir William Thomson, "the mechanical value of a cubic mile of sunlight is 12,050 foot-pounds, equivalent to the work of one horse-power for a third of a minute. This result may give some idea of the actual amount of mechanical energy of the luminiferous motions and forces within our own atmosphere. Merely to commence the illumination of three cubic miles requires an amount of work equal to that of a horse-power for a minute ; the same amount of energy exists in that space as long as light continues to traverse it; and, if the source of light be suddenly stopped, must be emitted from it before the illumination ceases." *

The same authority says: "Taking the estimate 2781 thermal units centigrade, or 3,869,000 foot-pounds,

---

* The mechanical value of sunlight in any space near the sun's surface must be greater than in an equal space at the earth's distance, in the ratio of the square of the earth's distance to the square of the sun's radius, that is, in the ratio of 46,400 to 1, nearly. The mechanical value of a cubic foot of sunlight near the sun must, therefore, be about .0038 of a foot-pound, and that of a cubic mile 560,000,000 foot-pounds. Similarly we find 15,000 horse-power for a minute as the amount of work required to generate the energy existing in a cubic mile of light near the sun.—*Thomson.*

as the rate per second of emission of energy from a square foot of the sun's surface, equivalent to 7000 horse-power,* we find that more than 0.42 of a pound of coal per second, or 1500 lbs. per hour, would be required to produce heat at the same rate. Now if all the fires of the whole Baltic fleet were heaped up and kept in full combustion over one or two square yards of surface, and if the surface of the globe all round had every square yard so occupied, where could a sufficient supply of air come from to sustain the combustion?—yet such is the condition we must suppose the sun to be in, according to the hypothesis now under consideration, at least if one of the combining elements be oxygen or any other gas drawn from the surrounding atmosphere."

12. **The Forms of Motor,** the special machines through which these transfers and transformations are effected, are the following:

(1) *The animal body* is a vital machine, of extraordinary complexity, self-constructing and self-repairing, and is automatic in its many and usually mysterious internal processes.

This machine is directed by conscious intelligence and will, and, when usefully applied to the production of work, is guided by the mysterious action of the mind. It effects conversions of energy through the processes of chemical action peculiar to the animal system.

(2) *The heat-engines,* including steam-, air-, gas-, and vapor-engines of various less familiar kinds.

In these machines, the potential energy of fuel is, by combustion, converted into the active form, and stored

* This is sixty-seven times the rate at which energy is emitted from the incandescent electric lamp at the temperature which gives 240 candles per horse-power.

in a gaseous or vaporous fluid, the variations of temperature, pressure, and volume of which result in the production, more or less efficiently, of mechanical power in readily applicable form.

The heat-engines do by far the greater part of the work of the world, and the steam-engine the main portion of that performed by thermodynamic operations.

Solar engines, so-called, are heat-engines in which the direct heat energy of the sun, instead of the stored heat energy of a combustible, is utilized through the action of a working fluid, as with other forms of machine of this class.

(3) *The water-wheels*, including the various classes of so-called vertical wheels, and the turbines; in which latter, the water, instead of entering "buckets," to be again poured out of them, passes continuously through channels, without reversal of motion.

These machines effect no transformations of energy; but simply turn it out of its natural course into an artificial channel of application. It is kinetic, as found, and remains kinetic until transformed in the course of its application to its intended purpose.

(4) *Tidal machines* are simply floats, rising and falling with the tides; or they are vertical water-wheels, working in tidal currents in precisely the same manner as those operated by ordinary running streams. They transfer, but do not transform, energy.

(5) *Windmills* are pneumatic turbines, especially fitted to take up the energy of moving air, and to transfer it, without transformation, to machinery of transmission, through which it is conveyed to its point of application.

(6) Electrical engines, electro-dynamic machines, dynamos and motors, as they are variously called, are

apparatus for transformation, converting the molecular energy of electricity into the mechanical form in such manner as permits its useful employment.

These machines, reversed, change the energy of mechanical power into the electrical form, and both directions of transformation in well-designed machinery result in a very efficient conversion of energy. As a rule, it is found much more satisfactory to derive the energy, initially, from a prime mover, by conversion into the electrical form, than to obtain it directly from the voltaic battery. Water-power or the combustion of fuel is vastly less costly than the combustion of zinc and the saturation of acids with its salts.

The purpose of this discussion is to describe, briefly and exactly, the characteristics of the animals as motors, to describe their methods of action and their sources of gain and loss of energy, and to present the principles of energy-production and transformation illustrated by them.

II.

THE ANIMAL AS A MACHINE AND A PRIME MOTOR.

13. The Animal as a Machine.—The engineer regards the animal system with peculiar interest, as a machine of singularly complicated structure, a heat-engine or other prime motor—he is not certain as to its classification—of extraordinary efficiency, and as the embodiment of scientific problems of the highest interest and greatest obscurity. In this curious machine, combustible matter in the form of the grains or other foods, is consumed, with resultant production of carbon dioxide and other chemical compounds of various degrees of oxidation, and there is thus made available thermal, mechanical, and probably electrical as well as vital energies, all of which energies find application in the processes of animal life, in the performance of work, external and internal, and probably in mental operations as well. Waste also occurs in the form of heat and the rejected potential energy of incomplete chemical action.

Considering the automatic system of the animal, apart from intelligence and will, it is, in the eye of the engineer, a self-contained prime mover, including its furnace, its mechanism of work and energy-development, and possessing mechanism of transmission of power peculiarly and exactly adapted to its purposes.

14. The Animal as a Prime Motor.*—Hirn was probably the first and the greatest of those who have sought to measure up the energies of living creatures, and to follow the transformations which occur in the processes of vital organization and animal exertion.†

The origin of heat in the bodies of living animals has been a matter awakening the greatest interest and curiosity from the earliest times. The ancients thought heat and light a part of the vital power, due to the creative act, and without immediate source in the processes of vital existence. They thought the act of breathing a necessary process of cooling and removal of excess of this spontaneously generated heat, due to the fact of life simply. Since the establishment of the principles of energy in modern times, however, the philosopher has only concerned himself as to the method of production of this heat, recognizing the fact that it must have its origin, as must all the exhibitions and expenditures of energy that accompany it in the living being, from the potential and latent energies of combustible substances subjected to the processes of digestion and assimilation in the body. The scientific man of later times sees in the vital processes a transformation of energies originating in a slow combustion at low temperature, with changes of form of the resulting energies which, though none the less certainly phases of the chain of vital phenomena which he studies, are not all fully understood, or as yet all detected and rendered evident by research. The chemical compositions of these combustibles are

* From Cassier's Magazine, Feb., 1892; by R. H. Thurston.

† La Thermodynamique et l'Étude du Travail chez les Êtres vivants. G. A. Hirn, Paris. *Bureaux des Revues*, 1887.

known; the quantities of energy which may be obtained by their perfect combustion to carbonic acid and water are well ascertained, and it only remains to determine the exact nature of the processes by which it is possible to effect their combustion at the temperature of the animal system, and to utilize by transformation the resulting power through those intermediate forms of energy-change which remain as yet undiscovered, and, in that sense, mysterious. We do not yet know how to produce combustion at a temperature of 98° Fahr., that at which combustion certainly does occur in the human system; or at the still lower temperatures at which such chemical changes go on in the bodies of cold-blooded creatures; nor do we know how to secure transformation of heat into mechanical and other forms of energy without sensible change of temperature and with high efficiency. In all our uses of heat-engines the wastes are a much greater proportion of the available energy than in any animal system, except where, as in some cases of application of the heat-energy of steam, for example, the wastes of the engine are, as in the human body, utilized for heating purposes.

The muscles when doing work, and all the glands, every organ, in fact, while performing its legitimate function, is found to become warmer; indicating the final appearance of whatever form of energy may be operating in the system in the form of heat. Heat is produced, apparently, in all the organs of the body, but in different degree, accordingly as their action is intense or deliberate. Those veins which return blood from working organs bring it back slightly warmer than the average for the whole system; those coming in toward

the heart from the skin bring back colder blood from that constantly refrigerated system of capillaries. The mean temperature of the venous blood entering the heart is about one degree warmer, in man, than the average for the whole system; between one and two degrees warmer than the arterial blood. The temperature of the body, as a whole, is automatically regulated by the system of nerves studied by Bernard; which causes the flow of blood toward any part to be accelerated when that part is cold, and retarded when it is too warm.

In every mechanism endowed with animal life, heat is produced and work is performed. It by no means follows that the work is the result of thermodynamic transformation; in fact, it seems impossible, in view of the fact that we have in the animal system no differences of temperature such as characterize and limit the action of the thermodynamic engine, that there should be a thermodynamic transformation. The heat would seem to be either a "by-product" or to be produced simply to insure uniform and sufficient temperature to permit the continuous and steady action of the vital powers and the machinery of the body. All the alimentary substances are combustible; but it is not a necessary consequence that they should be oxidized by a heat-producing combustion within the animal system. On the contrary, the quantity of heat which would be thus produced, added to the quantity of work performed by the vital organs, in digestion, nutrition, circulation of the blood,—itself an enormous quantity,—though reproducing the energy thus expended, as heat, and thus, in one sense, costing nothing—and in brain-work, to say nothing of wastes by conduction and

radiation to surrounding objects, the total amount of heat produced by such combustion would vastly exceed the quantity discharged from the body in any given time. This discrepancy is greater in cold-blooded animals than in warm-blooded; and, in many instances, the heat given out is probably too small in amount to account for combustion of any important fraction of the aliment of the system. The animal machine is not thermodynamic in the usual acceptation of that term, even if it be in any sense.

Mon. J. Beclard was probably the first to attempt to measure the relation of quantity and of transformation, thermodynamically, if such energy-transformations actually occur, in the animal machine. But he reached no definite result. Herdenheim suceeded little better; but Hirn found ways of investigation which gave real quantitative results of importance. A certain correspondence was found between work performed and heat exhaled; but nothing in his experiments gave indications of the method of production of that heat; and it is still impossible to say whether the heat is the direct product of oxidation of food, the result of oxidation of worn muscular and other tissue, or due to a number of thermal and other interactions occurring within the body and as yet beyond the reach of scientific observation. The disappearance of heat unquestionably established by Hirn's researches may or may not have been due to thermodynamic transformations. Whatever form of energy-transformation characterizes the vital machine, the wastes of energy take the final form of heat, and its quantity would, in any case, be reduced by the production of mechanical energy and the performance of work within and without the body.

In 1856–57 Hirn experimented with men engaged in regular work and at rest, and found that when at rest they produced a quantity of heat almost exactly, if not precisely, proportional to the amount of oxidation, as measured by the quantity of oxygen absorbed by them and exhaled in carbonic acid.

This was not precisely the case when they were at work. The principle of equivalence of energies then takes effect, and the measure of all the energy produced by oxidation is found in the sum of the heat discharged from the system and that energy of work which stands for the parts converted into dynamic forms.*

Hirn found that the quantity of heat generated by the human body at rest, whether that of men of middle age, or youth of either sex approaching maturity, was substantially the same under the same circumstances: about 5 calories per gramme of oxygen inspired and exhaled as a minimum, 5.2 as a maximum, and usually the latter figure. The differences may be ascribed to variations in observations, rather than to real differences of fact. Precisely the same quantities of air were measured as exhaled as were measured as inhaled, in all cases. A singular and significant fact was, however. discoverable in the results, as reported by Hirn: The quantity of heat produced per unit of oxygen absorbed and converted into compounds exceeds by a third the amount computed upon the basis of the experiments of Favre and Silbermann. This result would seem to indicate other sources of heat than combustion with oxygen. It may be due to

* L'Équivalent mécanique de la Chaleur. G. A. Hirn, 1858.

oxygen absorbed and exhaled through the skin; to the conversion of stored energies as yet undetected in the system; or to the combination of other elements, as carbon and hydrogen, through processes resulting in the production of heat.* It is to the latter cause that Hirn would ascribe this excess of exhaled energy. This subject remains still to be investigated.

The same individuals being set at hard work in a treadmill constructed for the purpose, in such manner as give the figures for a normal condition of labor, unforced but steady, and at a maximum for a day's work, gave out but about one half as much heat per unit of air breathed and of oxygen consumed, showing clearly the transformation of heat into work. The efficiencies of the human system, considered as a heat-motor or -engine, ranged, according to the condition and temperament of the subject of the test, from 17 per cent to 25 per cent when raising the load or themselves ascending, and rose to 30 and 40 per cent in descent. A lymphatic youth of 18 gave the lowest figures; a strong man of 47 the highest. These results all exceed those obtainable as yet from the most economical forms of existing gas- or steam-engine, in which 20 per cent may be taken as about the contemporary limit of their efficiency as heat-engines.

To fully secure this efficiency in the human body as a heat-engine subjected to the accepted laws of thermodynamics would demand a temperature within its working parts not far from 140 Cent. (284° Fahr.), or far above the boiling-point of water. This fact is crucial as a proof that the transformations of energy

* See Sarason: *Revue Scientifique*, 1887, page 306 *et seq.*

in the animal system are not, in the accepted sense, thermo-dynamic. They must involve as yet unknown processes and methods, and must be free from the control of thermodynamic principles, as we are accustomed to denominate them. The "second law of thermo-dynamics" is here evaded.

In those cases in which work was done, the producduction of heat was as much less than that anticipated, as computed from the engineers' and the physicists' experiments, as, in the case of rest, that figure was exceeded, falling in the latter case to from 2.5 calories to 3.5 per gramme, varying with the individual and his familiarity with the work, and consequent efficiency as a machine.

Thus the investigator shows that while the animal system is unquestionably a machine producing and utilizing energy by transformation, it possesses some peculiarities and conceals some secrets that science has still to discover through exact methods of research. It further has become evident that these methods of production and utilization of energy include some which are very different from those familiar to us, as exhibited in our inanimate heat-engines, and which, once discovered and given application, should that prove practicable in artificial machines of this class, will probably prove enormously advantageous in the saving of costly energies now so largely wasted. Could we discover and apply these methods in displacing our heat-engines, it would give us direct transformations of energy into work at low temperatures, with little or no wastes, and thus enormously extend the period of human life on this globe, as well as its productiveness. It will be an interesting question for the electrician

and the engineer to settle: whether these as yet mysterious processes are not electro-dynamic or related phenomena.

15. **The Processes of the Vital Machines** employed in the development of power result mysteriously in the production of heat, light, electricity, and dynamic energy by methods still unknown, and with an efficiency of development, transformation, and application frequently, if not always, much greater than has been yet attained by any of the machines devised by man to effect similar results. Mechanical power is exerted at less cost in potential energy supplied than in the steam-engine; heat is evolved as the product of combustion or other action at a low temperature, and with insignificant waste by non-utilization in the processes of the animal economy; light is produced by glow-worms and fire-flies without sensible loss in accompanying thermal or other energy; and electricity, probably the motor energy of the machine, is produced with similar wonderful economy by processes of which we have no knowledge. Combustion at ordinary low temperatures, in the tissues of the body; chemical combinations of other kinds in the digestive organs, by the action of peptic substances in solution in the fluids of the system, and other processes unknown, as yet: these evade the inevitable losses of thermo-dynamic operations in the vital machine, and effect results which are never economically obtainable by the machines of the inventor and mechanic. These constitute a standing riddle and challenge to the man of science and the engineer.

Lavoisier, as early as 1789, asserted that animals are composed of combustible substances, and that their life

is based upon chemical action involving the slow combustion of the carbon and hydrogen of their food and muscle; respiration furnishing the needed oxygen—an element discovered by him three years earlier. Rumford, in 1797, stated that animals, considered as machines, were efficient prime motors, and in 1799 published his discovery of the identity of heat with mechanical energy and his approximation to the value of the mechanical equivalent; and Scoresby and Joule, and especially Hirn, later completely confirmed his views on these points.*

Modern research shows that the evolution of heat is at least an invariable accompaniment of all action of the animal system—also even of the brain and spinal cord. Thought and manual labor, in the case of the human machine, are alike productive of increased temperature and of accelerated exhalation of carbon dioxide from the lungs and of salts from other organs. Whether these chemical actions are direct results or simply incidental to intermediate transformations of matter and energy is as yet not fully determined. The effect of exercise is invariably to increase greatly the consumption of oxygen, and the elimination of carbon dioxide, and the temperature of the body, within narrow limits; regulation being effected by exudation of perspiration and its evaporation. Other effects of increased exertion of the muscular system are the promotion of digestion, the consumption of accumulated combustible matter, as the fats, and increased rapidity and thoroughness of blood circulation and of nutrition,

---

* On these points, see Seguin and Lavoisier (Premier Mémoir), Rumford's Essays, and *Philosophical Magazine*, 1846.

which are the essentials to efficient action of the machine as a whole. The wonderful self-adjusting power of the system makes these actions effective even locally; and the exercise of one member or part of the machine produces increased circulation, increased degeneration, and at the same time increased blood-supply and nutrition of the part thus compelled to supply energy.

The muscular system constitutes about 40 per cent of the weight of the body, and contains blood to the amount of one third this weight, or 12 to 15 per cent of the whole weight of the body. The wear of this muscular tissue gives rise to a demand for the nitrogenous foods to supply the waste, and thus produces an appetite for lean meats or for vegetable foods rich in gluten. The nervous tissue, the system of intercommunication and transfer of energy from part to part, is also subject to wear; and this waste is supplied by the phosphatic foods, as animal brain, marrow, nerve, and glandular or other white meats, and as the fruits and the grain-foods, the peculiar diet of the human and especially of the brain-working creature. Overuse of the muscles or of the nervous system reduces their powers of recuperation, repair, and general nutrition; and it is for this reason that labor and exercise should be carefully restricted within those limits marked by the appearance of symptoms of exhaustion. Highest efficiency of the animal, as of any other machine, can be permanently maintained only when the conditions of maximum perfection of parts and of operation are ascertained and insured. The selection of proper foods is as essential to the successful maintenance and use of the animal machine as the securing of good fuel for use in the heat-engines; attention to diet and the adjust-

ment of the periods of employment to best effect are as important as the supply of the best coal and the periodical stoppage and repair of the machinery in a mill or factory.

The elimination of nitrogen and carbon dioxide is, in some as yet uncertain way, a gauge of the quantity of useful and lost work of the animal machine. Liebig states in his Animal Chemistry (1843) that the excretion of nitrogen is proportional to the destruction of tissue, and Lehman states in his turn that he finds this excretion increased by exercise. Fick and Wislicenus, on the other hand, assert that the animal is a heat-engine, and that the performance of work affects the elimination of nitrogen slightly, but increases that of carbon dioxide enormously, and this view is confirmed by Frankland and by Houghton; while Dr. Parkes indirectly gives similar testimony in the statement that work is done by the consumption of other than nitrogenous foods, the elimination of nitrogen being due to waste of tissue; that of carbonic acid to combustion resulting in thermodynamic action. Incidentally, Liebig also confirms this idea by his statement that the exhalation of nitrogen goes on long after work has ceased.* Dr. Pavy, on the other hand, found by experiment on two well-known pedestrians that their excessive exertion produced greatly increased elimination of nitrogen—apparently a consequence of the breaking down of tissue. He concludes that the body is a true heat-engine, but he finds it capable apparently

* See Frankland's Origin of Muscular Power; Houghton in the *Lancet*, 1868; Parkes in the *Medical Times*, 1871; Flint on Muscular Power, 1872; Pavy on Muscular Power, 1878.

of performing more work than the food would seem competent to do. In these cases it would seem very possible that the observed excess may come of consumption of tissue in addition to food; the waste being gradually repaired during a later period of prolonged rest, with food-consumption above the normal rate.

Dr. Flint, who paid much attention to this subject, concluded, as the result of the study of the working of the muscular system of a celebrated pedestrian (Weston), about 1870, during a walk of 318 miles in five days, weighing all foods and excretions and noting their composition, that it is as yet impracticable to intelligently compare the force-value of foods with the work of the muscular system; that such estimates, as now customarily made, account only for a part of the work, even leaving out of consideration the energy of other (vital and nervous) actions; that exercise always results in waste of muscular tissues, which may not be repaired at the time; and he also believes that the source of energy is the wasted tissue, and, indirectly only, the nitrogenized food which supplies the waste.

Dalton takes the production of heat in the body at rest, per hour, as about 1.28 British heat-units per pound of its weight. Houghton estimates the work done in walking at one twentieth of the weight of the body in pounds multiplied by the number of feet walked per hour; and it would seem possible, from Flint's computations, that about ten per cent of the total energy-expenditure takes place in the brain and nervous system in the case of man, although that author does not so take it.* The processes involved in the operation

* Source of Muscular Power, pp. 100–103.

of the animal mechanism, to say nothing of its mental part, are too complicated and obscure to permit at present any very accurate statement of their nature, methods, or results.

16. **The Efficiency of the Animal System,** considered as a heat-engine—a probably incorrect assumption—is very high as compared with the machines of that class constructed by man. Helmholtz concluded from the experiments of Hirn that the thermodynamic efficiency of the system is about 0.20, confirming Hirn's own earlier deduction that it is more efficient than the steam-engine as ordinarily constructed. The fact, however, that the body is sensibly uniform in temperature throughout, and that the more work done the more rapid the circulation, and the more certain this uniformity of temperature, seem to prove it impossible that such thermodynamic processes are carried on in the animal system as are familiar to us in our heat-engines, in which the maximum possible efficiency is proportional to Carnot's function—range of temperature divided by maximum absolute temperature. Whatever its method of operation, therefore, the animal machine evades Carnot's law, and must illustrate some as yet undiscovered process of energy-transformation.

17. **The Work of the Animal Machine** is measured in "horse-power"—a rate equivalent to 550 foot-pounds per second, 33,000 per minute, 1,980,000 per hour; 75 kilogrammeters per second, 4500 per minute, 270,000 per hour, in British and metric measure respectively; the latter, however, being, as will be seen by comparison, one seventieth less than the former. Its measure may also be taken as a *day's work*, which may have widely different dynamic values in different cases.

The horse, if of average weight and condition, should do a day's work at the rate of about two thirds of a horse-power unit, or 22,000 to 25,000 foot-pounds per minute for the day. A powerful horse may give a full horse-power, and any animal may do for a short time vastly more than its average rate of work. A man rated at from a sixth to a tenth horse-power can, for a minute or two at a time, perform a full horse-power, or even more.

The daily work of the animal, at its best, depends upon its exact accommodation to most favorable conditions for the development of the best work of the individual, and upon its size, natural strength, endurance, and spirit. These qualities in turn are dependent upon the breed, the state of health, and the general condition of the animal, its food, its environment, the weather, the climate, and the adaptation of its load to its habits and training. While at work the main elements of most effective operation are the load and the speed adopted, at the time, and its distribution, day by day and hour by hour. At maximum load the animal does minimum work; at maximum speed it can carry no load; at some intermediate load and speed it gives maximum work, and this maximum varies with the time of working, day by day. It is higher for short, lower for long, working-days. For continuous work it is usually assumed that eight hours a day, at one third maximum speed and under one third maximum load, gives highest results; but this is true only under most favorable conditions, with animals capable of doing a full day's work, day by day, continuously without loss of strength. In many cases four hours, and sometimes even one, constitute a fair day's work.

Animal power is most remarkably developed in the

birds of fast or of long flight. A man can exert 0.25 horse-power for a few minutes at a time, 0.15 horse-power by the hour—which, at 150 pounds weight of the man, would require 600 to about 700 pounds per horse-power. The horse weighs 1500 or 2000 pounds per horse-power; but the birds develop power at the rate of probably less than one third those figures for the former, and one eighth or one tenth for the latter. Falcons fly 60 miles an hour, pigeons 35 to 60 for hours together, and the albatross accompanies fast steamers thousands of miles without halt or rest. The birds weighing probably 100 to 200 pounds per horse-power can carry for a time an added load of 30 to 50 per cent, as when the carnivorous birds carry away their prey.

According to M. Fourier, the daily work of a good horse has a maximum, under the best load for each speed, at about 0.90 (2.95 feet) meters per second, or 3200 (10,596 feet, 2 miles, nearly), an hour. Taking this maximum as unity, he gives the following as probable values of work per pound at other speeds:*

SPEED PER HOUR.		DAILY WORK.
Metres.	*Miles.*	
2,000	1.25	0.69
3,200	2.00	1.00
4,000	2.50	.99
6,000	3.75	.94
8,000	5.00	.83
10,000	6.25	.68
12,000	7.50	.51
14,000	8.75	.33
16,000	10.00	.18
18,000	11.25	.07

* Génie rural, Hervé Mangon; t. III., p. 175.

Where the animal must develop maximum power continuously at any considerable speed, the number required for a specific work will always be greatly increased. Thus, in coaching, the proprietors of mail-coaches, even on the admirable highways of Great Britain, maintain one horse per mile of route for each coach and worked in fours, so that, going and returning, each travels 8 miles per day, working only an hour or less each day on the average. The coach weighs, loaded, two tons, and its coefficient of friction on good roads is about 0.035. Draught-horses at 2.5 miles an hour are expected to do seven times the work of coach-horses at 10 miles.*

18. Tabulated Figures for the work of men and animals follow, as given by Coulomb, Navier, Poncelet, Rankine,† and others. Tables A, B, C, D, etc.

According to Mr. Box, the work of men and animals may be taken, in foot-pounds per minute, as:

		Hours per Day.			
	V	4	6	8	10
Man at a winch.......	220	3,730	3,030	2,640	2,370
" " " treadmill....	130	5,510	4,490	3,890	3,460
" " " capstan......	118	4,420	3,590	3,100	2,770
Horse at a capstan....	176	24,780	20,260	17,520	15,670
Mule " " "	180	16,530	13,460	11,680	10,390
Ox " " "	120	22,044	17,980	15,570	13,920
Ass " " "	157	6,060	5,610	4,850	4,320

The average effort of a man at a winch should not be assumed above 15 pounds for a day's work, although more than double that figure may be easily attained for a brief period. From 20 to 30 turns a minute is a

* Barbour's Cyclopædia of Manufactures.

† Steam Engine, Chaps. II., III.

A. WORK OF A MAN.—RANKINE.

Kind of Exertion.	*R* lbs.	*V* ft. per sec. and per min.	$\frac{T''}{3600}$ (hours p. day).	*RV* ft.-lbs. per sec. and per min.	*RVT* ft.-lbs. per day.
1. Raising his own weight up stair or ladder	143	0.5 30.0	8	72.5 455.0	2,088,000
2. Hauling up weights with rope, and lowering the rope unloaded	40	0.75 45.00	6	30 1800	648,000
3. Lifting weights by hand. ...	44	0.55 33.00	6	24.2 1452.0	522,720
4. Carrying weights upstairs and returning unloaded....	143	0.13 7.80	6	18.5 1110.0	400,000
5. Shovelling up earth to a height of 5 ft. 3 in...... ...	6	1.3 78.0	10	7.8 468.0	280,800
6. Wheeling earth in barrow up slope of 1 in 12, ½ horiz. veloc. 0.9 ft. per sec., and returning unloaded........	132*	0.075 4.50	10	9.9 594.0	356,400
7. Pushing or pulling horizontally (capstan or oar).......	26.5	2.0 120.0	8	53 318.0	1,526,400
8. Turning a crank or winch....	12.5 18.0 20.0	5.0 & 300 2.5 & 150 14.4 & 864.0	? 8 2 mins.	62.5; 3750 45; 2700 288; 17280	... . 1,296,000 ....
9. Working pump..............	13.2	2.5 & 150.0	10	33; 1980	1,188,000
10. Hammering.....	15	?	8?	?	480,000

* Net weight of earth in the barrow.

B. PERFORMANCE OF A MAN IN TRANSPORTING LOADS.

Kind of Exertion.	*L* lbs.	*V* ft. per min. and per sec.	$\frac{T}{3600}$ (hours p. day.)	*LV* lbs. conveyed 1 foot.	*LVT* lbs. conveyed 1 foot.
11. Walking unloaded, transport of own weight............	140	300 5	10	700	25,200,000
12. Wheeling load *L* in 2-whld. barrow, return'g unloaded.	224	100 1⅔	10	373	13,428,000
13. Ditto in 1-wh. barrow, ditto..	132		10	220	7,920,000
14. Travelling with burden......	90	2½ 150	7	225	5,670,000
15. Carrying burden, returning unloaded..................	140	100 1⅔	6	233	5,032,800
16. Carrying burden, for 30 seconds only................	252 126 0	0 & 702.0 11.7 23.1 & 1386.0	....	0 1474.2 0	....

common range of speed, the handle being 15 to 18 inches long, and about 3500 foot-pounds per minute a fair performance.

Mr. D. K. Clark gives the following as the work, for one day, of a laborer, under the specified conditions:

Load. Kind.	Weight.	Work.
Carrying brick...	106 lbs.	600 mile-lbs.
" coal....	100 "	342 " "
Loading wagon..	100 "	270 " "
" boat....	190 "	1230 " "

One man breaks 1.5 cubic yards of stone, or quarries 5 to 8 tons of rock per day.

The walking speed of man is three to four miles an hour. Running eight miles an hour is a common limit; but 100 miles in a day for a week together, and 11½ miles in one hour, have been attained by practised pedestrians. "One hundred yards dash" has been accomplished at the rate of 20 miles an hour. A skater has attained in one mile over 20 miles an hour; on the bicycle about 30 miles an hour has been reached; 50 miles has been made in 2½ hours, 100 miles in 6 hours, 388 in 8 hours, 900 in 72.4 hours.* Swimming long distances only an average of about one mile an hour has been made by man; but the porpoise plays about the bow of ocean steamers making 14 and 15 miles (statute) or more per hour.

Ruhlmann finds the work done by a Prussian soldier on the march, carrying 64 pounds, to be about 3,000,000 foot-pounds per day. Various authorities give about

* Whittaker's Almanach, 1893.

2,000,000 foot-pounds when ascending mountains, and from 1,250,000 to 2,500,000 turning a winch.

It is customarily assumed that a horse may develop 22,500 foot-pounds per minute throughout a day's work of eight hours; will carry 250 pounds 25 miles in a day of eight hours; and that 1500 pounds, wagon included, is a good load for a horse drawing it on good roads 25 miles a day of eight hours. The regular load rarely exceeds one half the maximum. The load which can be raised by a bird is said to be about one half its own weight as a maximum.

Weisbach states that a man can walk, unloaded, ten hours a day at 3½ miles an hour; carrying 80 pounds, he can walk seven hours at two thirds that speed. He can walk upstairs, unburdened, at the rate of 0.48 foot per second, eight hours a day, and performing 1,935,360 foot-pounds of work per day, assuming his weight to be 140 pounds. He can traverse, without load, 12.5 times as much space horizontally as vertically. A day's work with a "rammer," such as is used by paviors, is given as 1,142,400 ft.-lbs. Turning a crank, man accomplishes 1,175,040, with a mean effort of 16 pounds and a speed of 2.4 feet per second during a working day of eight hours. On a capstan an able-bodied man, also, can perform 1,382,400 foot-pounds of work per day. On the treadmill he attains 1,750,000 foot-pounds.

The estimates of General Jouffret yield the following*: "According to the *Guide Joanne*, the ascent of Mont Blanc, starting from Chamounix, is effected in seventeen hours, resting-spells not included. The difference of level is 3760 metres. A person ascending

* Théorie de l'Énergie; Paris, 1885.

who has a mean weight of 70 kilogrammes produces, then, in order to rise, a work of $3760 \times 70 = 263{,}000$ kilogrammetres. This work is borrowed from the heat that the carbon and hydrogon contained in the food eaten disengage upon being burned in the lungs. For the sake of simplicity, if we reduce the entire energy to a combustion of carbon, and recall that a kilogramme of the latter furnishes 3,000,000 kilogrammetres, we find that the 263,000 kilogrammetres represented by the ascent correspond to a consumption of 94 grammes of coal—a consumption that should be added to the normal rations necessary for the operation of the organs during a state of rest. Such consumption is 8.35 grammes per hour, or 142 grammes for the seventeen hours. The total consumption of coal is 256 grammes, representing 708,000 kilogrammetres. The performance, then, is

$$\frac{263{,}000}{708{,}000} = 37 \text{ per cent.}$$

"The performance of the human machine drops to 21 per cent when we consider a period of twenty-four hours composed of ten hours of work and fourteen of rest, and a mean daily work of 280,000 kilogrammetres.

"The cannon, considered as a machine, is incomparably superior to a steam-engine as regards the time necessary to produce a given quantity of mechanical work.

"Thus, for example, the 100-ton cannon develops in *one hundredth of a second* a quantity of work equal to that which would be yielded by a 47-horse-power steam-engine *in one hour.* A man of average strength is still lighter than an ordinary steam engine of equal power,

but he is much inferior to the other animals of creation, and particularly to insects.

C. WORK OF A HORSE AGAINST A KNOWN RESISTANCE.

Kind of Exertion.	R	V	$\frac{T}{3600}$	RV	RVT
1. Cantering and trotting, drawing a light railway carriage (thoroughbred)	min. 22½; mean 30½; max. 50	14⅔	4	447½	6,444,000
2. Horse drawing cart or boat, walking (draught-horse)	120	3.6	8	432	12,441,600
3. Horse drawing a gin or mill, walking	100	3.0	8	300	8,640,000
4. Ditto, trotting	66	6.5	4½	429	6,950,000

D. PERFORMANCE OF A HORSE IN TRANSPORTING LOADS HORIZONTALLY.

Kind of Exertion.	L	V	$\frac{T}{3600}$	LV	LVT
5. Walking with cart, always loaded	1,500	3.6	10½	5,400	194,400,000
6. Trotting ditto.......	750	7.2	4½	5,400	87,480,000
7. Walking with cart, going loaded, returning empty; $V = \frac{1}{2}$ mean velocity	1,500	2.0	10	3,000	108,000,000
8. Carrying burden, walking.......	270	3.6	10	972	34,992,000
9. Ditto, trotting.................	180	7.2	7	1,296	32,659,200

The average weight of a horse or an ox may be taken as thus:

Light carriage-horse.......... 800 lbs.
Heavy " .... 1200 "
Light draught-horse.......... 1000 "
Heavy " .... 1600 "
Ox........................ 1000 "

The horse has galloped a mile in 1 minute 43 seconds, or at the rate of 35 miles an hour, and trotted a mile in 2 minutes 4 seconds, or 29 miles an hour.

An Austrian army officer rode, in June, 1893, from Vienna to Berlin, 388 miles, in 71.33 hours, or 5.45 miles an hour, resting an hour in twelve, but losing his horse after the race was concluded. The "cyclists" have beaten this record.

Rennie found the hauling power of a draught-horse weighing 1200 pounds was equal to about 108 pounds at 2.5 miles an hour, or 22,300 foot-pounds per minute, for eight hours per day, a 20-mile haul. This is a little over two thirds of a Watt "horse-power," at which value Rennie rates the average draught-horse, and this is taken to be, ordinarily, five times the power of a man. Between 2½ and 4 miles an hour, the hauling power of the horse is nearly inversely as the speed.

The mule carries a load of 200 to 400 pounds, and its day's work consists, usually, in the transportation of the equivalent of 5000 to 6000 pounds one mile. The ass carries 175 pounds and upward, and the day's work is the equivalent of 3000 to 4000 pounds one mile.

According to Weisbach, a horse should be able to carry 240 pounds on its back 3.5 feet per second ten hours a day. Carrying 160 pounds he should be able to trot 7 feet per second seven hours a day, doing, in the day, ten per cent less work than before, nearly.

The pulling power is said to be, as a rule, about one fifth the weight of the animal. Its usual effort, in the case of the horse at least, is seldom in excess of one tenth, or about one half the maximum. One hundred pounds is a common pull for the average horse in draught vehicles.

19. Effective Methods of Application of man-power are sought by the engineer. The best is considered to

be that of Coignet; who arranged hoists in such manner that the men employed would go up ladders or stairs to the summit of the lift and then, by their weight applied to the "fall" of the tackle used, descending to the ground thus suspended, the work of their descent would be transmitted to the hoist and raise the load. Tables B, C, D, are for common roads. Rankine gives as the approximate relative power of various animals the following: The ox draws a load about equal to that of the horse, the mule one half, the ass one fourth. The ox moves at two thirds the speed of the horse, the mule the same velocity as the horse, the ass the same; making their respective working powers as 1 to $\frac{2}{3}$, to $\frac{1}{2}$ and $\frac{1}{4}$, respectively. In all cases, the practical limit is determined by the method of application, the character of the vehicle, if any, used, and the adjustment of the animal to its surroundings, as well as by its own physical characteristics. Animals do their work mainly by draught of vehicles. Its amount depends largely upon the character of the road traversed. The effort required may be taken as approximately as follows, for total loads, including the vehicle:

Good country road.........	50 lbs. per ton.
Macadamized surfaces......	40 " " "
Asphalt pavements........	38 " " "
Wood "	35 " " "
Granite tramways....	27 " " "

Granite pavement, dry, is less likely to cause falls than either wood or asphalt; when wet, wood is best in this respect. Macadamized and earth roads are safer than either of the pavements.

20. The Draught of Vehicles is a case of rolling friction.* Morin, who made very extended experiments, states its laws as follows:

(1) On hard surfaces, as paved and macadamized roads, the resistance is directly proportional to the weight of vehicle and load, inversely proportional to the diameter of wheel, and independent of the breadth of wheel-tire. It increases with velocity.

(2) On soft ground the resistance increases inversely as the breadth of tire. It does not sensibly vary with velocity. Morin concludes, also, that the line of draught should be horizontal.

Dupuit, on macadamized roads, found the resistance to vary nearly inversely as the square root of the diameter of wheel and directly as the load. He found the resistance on pavements to be increased at high speeds by the concussions incident to rapid movement. Clark obtains a somewhat less simple law, which he expresses thus:

$$R = a + bv + \sqrt{cv}. \quad . \quad . \quad . \quad . \quad (1)$$

The work of hauling is then

$$U = Rs = (a + bv + \sqrt{cv})vt. \quad . \quad . \quad . \quad (2)$$

This formula is deduced from the experiments of Macneil on "metalled" roads.† The values of the constants are, in British measures, $a=30$; $b=4$; $c=10$ pounds per ton, v being given in miles per hour, t in hours.‡

* Friction and Lost work; Thurston, p. 84.

† Clark's Manual, p. 964.

‡ Parnell on Roads, p. 464.

The resistance of all vehicles on common roads and streets is principally resistance to rolling, their axle-friction being comparatively small. The work of hauling is, then,

$$U = Fs = fWs = fWvt. \quad . \quad . \quad . \quad . \quad (3)$$

The draught of vehicles loaded in any stated manner may be made comparatively easy or difficult by proper or improper methods of attachment of the animal to the vehicle.*

The general principles to be observed are the following:

(1) In hauled loaded vehicles, the line of traction should be made such as to make the hauling power dependent upon adhesion between the animal and the ground equal to the resistance of the vehicle, with some margin of insurance against occasional slipping.

(2) The heavier the load, if in excess of the hauling power due the animal's weight, the more should that weight be reinforced by so adjusting the line of traction that it may have a vertical component tending to raise the load and increase the holding and hauling power of the feet of the animal.

(3) With loads lighter than those demanding the total adhesion due the weight of the animal, the line of traction should be so located that the haul, and, if possible, the load itself, may take off a part of the animal's weight.

Thus, with a two-wheeled vehicle the load may usually be so distributed as either to be carried, in part,

* Mr. T. H. Brigg has made a study of this point, with interesting results. Trans. Am. Soc. M. E, 1893.

by the horse, or to balance a part of the weight of the animal; the latter either carrying part and hauling part of the load, or hauling the load and, with it, a part of its own weight, transferred, by the inclined upward line of traction, to the load. The former disposition is obviously suitable for heavy loads and steep gradients, the latter for light loads and level or falling stretches of road. Heavy wagons should be handled in such manner as to give the former, light carriages the latter, adjustment. It would probably, in the case of the heavy vehicle be well to provide, if practicable, for the change of the line of pull to suit the load and gradient, as has been practised by Mr. Brigg; who finds, in some cases, a loss of one half the mechanical efficiency attainable, due to inappropriate methods of attachment of the animal to the vehicle.* He concludes:

"The resistance which a horse can overcome depends upon the following conditions: (1) his own weight; (2) his grip; (3) his height and length; (4) direction of trace; (5) his muscular development, which determines the power to straighten the bent lever represented by his body and hind legs against the two resistances, the vehicle through the trace attached to the shoulder and the hind feet against the ground.

"To pull through a very low trace, or to have a man, or even two or three men, on a horse's back is advisable and even necessary if a horse is expected to haul a load requiring the full force of his muscles at any particular moment—and for the moment, under such conditions, he would be able to draw a much greater load than without the added weight. But any person can

* Ibid.

see that the animal could not travel far with any vehicle if he must carry three men on his back in addition to hauling his load."

"Therefore, to deal justly with our horses, we should not only study cause and effect, but should devise some means by which, automatically, every possible advantage could be given to the horse at all times.* Otherwise there must be a constant waste of energy, tiring the horse prematurely and increasing the chances of his stumbling and falling."

These principles are thus illustrated by Mr. Brigg:

In the accompanying figure, let the horse be harnessed in the usual manner and driven up hill.

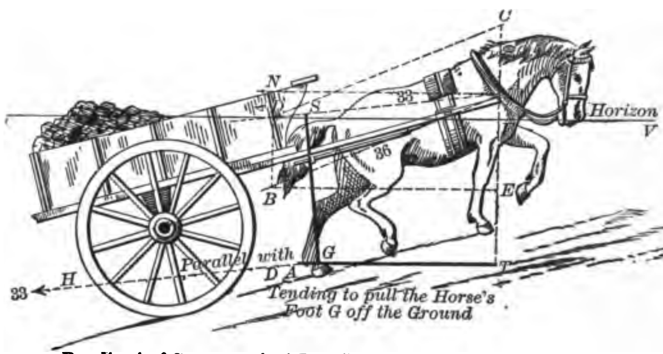
Suppose that the horse is exerting a force of 36 lbs. through *AB* in a line from the hame to the centre of the wheel. Let *AC* represent the vertical depression necessary to hold down the shafts. Since *AB* and *AC* are the forces necessary to produce motion, by completing the parallelogram *ACDB* we find that *AD* represents the resultant of the forces *AC* and *AB*. Thus we determine one arm of the lever, *GS*, acting against *GT*, the other arm. *GS* is a line drawn at right angles from the resolved angle of force *AD*.

If the load had been balanced on the axle, then, regardless of the angle of trace or hame-chain, the angle of draught would be through *AB* to the centre of the wheel. Then a line at right angles with *AB* to *G* would have been the short arm of the lever, which would have enabled the horse to have pulled a much greater load than is possible with the longer arm, *GS*. But,

* Mr. Brigg had already devised and applied such a system of self-adjustment of the harness as to secure this effect.

the load being behind the axle, the forward weight of the animal is reduced by the lift of the shafts at *A*, and the result is the same as if the traces had been put up at the point *D*, and the load, with a 33-lb. pull through such a trace, would be exactly balanced.

Let *UV* represent the horizon passing through the point *D*. If *DA* represents 33 lbs., then *FA* will



Resultant of Components A B and A C as A D, or N D added to Horse's Weight, N D equals 4 taken from the Load and Carried by the Horse.

FIG. 1.—HAULAGE OF VEHICLES.

represent 4 lbs., so that 4 lbs. must be added to the horse's natural weight by the pull *AD*. Or, if the pull through the trace *AB* is 36 lbs., then, drawing *BE* parallel with the horizon *UV*, *EA* (14 lbs.) will represent the depression due to a 36-lb. pull through *AB*. But when the lift due to the shafts, 10 lbs., is deducted from the depression of 14 lbs., there remains as before an increased weight of 4 lbs. on the horse.

When the horse is pulling with the same force upon a level, as in Fig. 2, we find very different results. Let *PA* be the direction from the hames to the centre

of the wheel and representing a 36-lb. pull. The load having been moved farther to the rear, the lift at the belly-band is still 10 lbs. at *P*—the load is moved backward to shift the centre of gravity. The resultant of the two components *PA* and *PB* is *PC*, and *PC* now equals about 35.9 lbs., whereas the resultant *AD* in Fig. 6 is only 33 lbs., or 2.9 lbs. less than on the level. It will now be found that 36 lbs. pull through *PA* will increase the horse's weight 4.5 lbs., represented by *PO*, which is determined by drawing *AO* from *A* parallel with the horizon, cutting the line of gravity *PE*.

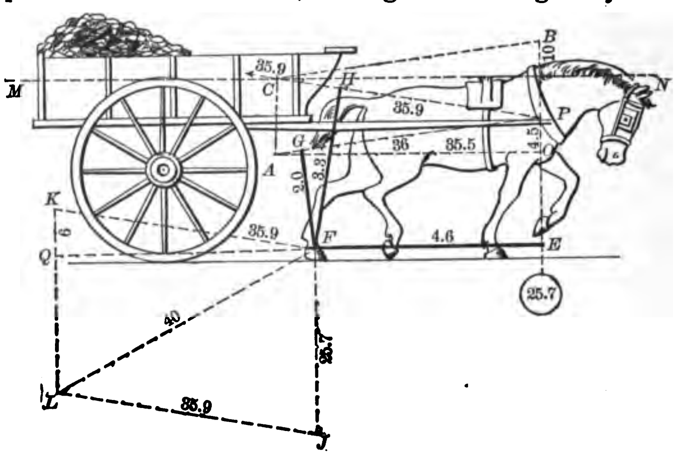


FIG. 2.—HAULAGE OF VEHICLES.

But, as the disposition of the load is such that 10 lbs. are taken from the horse, it is obvious that, if only 4.5 lbs. are put back by the stated pull of 36 lbs., the horse has still 5.5 lbs. less than his natural weight in Fig. 2, while in Fig. 1 he has 4 lbs. more than his natural weight.

If the load be shifted to the front end of the cart, as indicated in Fig. 3, the resultant of the forces *PJ* and *PK* lies in the direction of *PL*, and the added

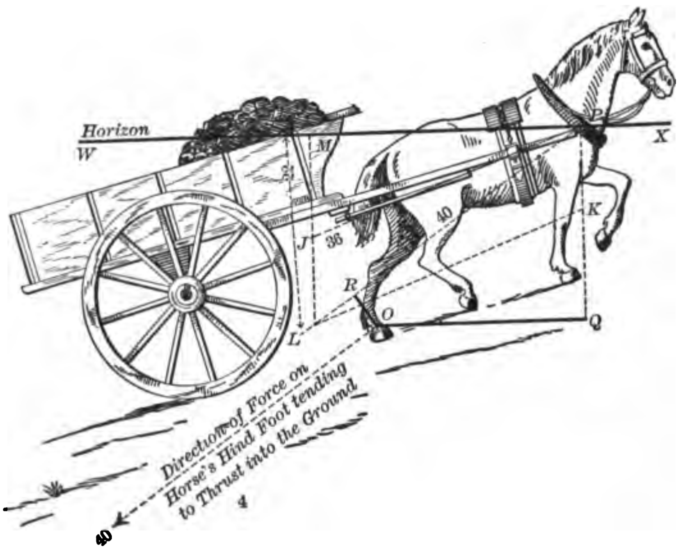


FIG. 3.—HAULAGE OF VEHICLES.

weight on the horse is 22 lbs. instead of 4 lbs. as in Fig. 1, tending to thrust his hind foot into the ground at *O*, and he is able to pull 40 lbs. as against 33 lbs. under the conditions indicated in Fig. 1.

It will be observed in Fig. 1 that the point of application of force *A* (the hame) is above the horizontal line *UV*, drawn through the point *D*, this being the point at which the traces might be fixed with an advantage equal to having them attached to the axle when the given lift is exerted at *A*, with a lift at the belly-band as set forth; whereas *P*, the point of appli-

cation of force in Fig. 2, is now much below the horizontal line *MN*, drawn through the point *C* on the resultant, or virtual line of draught. Comparing the triangles *ABE* (Fig. 1) and *PAO* (Fig. 2), *AB* and *PA* represent the pull through the traces, and, although the force is the same—36 lbs., the result is different.

If *AB* in Fig. 1 represents a 36-lb. pull, and *AC* a 10-lb. lift, then *AD* (33 lbs.) is the resultant direction of force applied by the animal. A 36-lb. pull through *AB*, together with a lift of 10 lbs. through *AC* or a pull of 33 lbs. through *AD*, will both be effective in lifting 2.6 lbs. from the horse's fore quarters.*

Thus the animal may be very effectively aided, or may be totally incapacitated by good or bad adjustment of the line of traction. In all cases this line should be given such inclination as will insure increased pressure of the animal upon the ground for heavy pulling, and decrease its weight in the opposite case, just to the extent required to make adhesion ample without unnecessary surplus.

21. Muscular Power varies enormously with the animal, its condition, habits of exercise, and other circumstances; but the results of many experiments indicate that the muscles of the human body have a power measured, in good condition, by a maximum of not far from 10 kilogrammes per square centimetre, and averaging 7 or 8 (142,110,114 pounds per square inch respectively). The influence of exercise and custom on the working power of the muscle is enormous, in some cases being found to vary in the proportion of

* Ibid.

one to at least three.* This quantity of work done has no ascertained relation to the value of the energy of the foods consumed; although the work which an animal can do is dependent upon the quantity of energy-producing food which it can digest and assimilate under the conditions to which it is subjected while at work. The stored energy of the foods varies, according to Frankland, from about 500 kilogrammes per gramme, or 45 foot-pounds per ounce, for lean meats, to three times this quantity for the grain-foods and to six times this value for butter; but the total need of the system determines the kind and quality of food desirable at any given time and for any given case. In general the use of the grain-foods is, from a scientific and possibly from a physiological point of view, most productive of useful power in both man and the domestic animals. Where the work is severe and long-continued no time is allowed for proper digestion and assimilation, and in such cases special care must be taken to provide the best conditions for insuring endurance. It is in illustration of this point that the case of the Arab living on the coffee-berry, and the pedestrian on long walks living entirely on the same material in the form of a beverage, may be referred to. The warm drink is at once stimulus and food, and demands little energy in digestion and assimilation. A permanent dietary, however, must contain all the elements demanded for nutrition of all parts of the system in proper proportions, and must at the same time provide the needed mechanical and other stimuli of all the organs of the body. The *whole* wheat used by man, fruits, and the

* Nipher on Strength of the Muscle, *Am. Jour. Sci.*, Nov. 1875.

grains consumed by horses and cattle are considered to be most perfect examples of these foods. Eggs and milk, among animal foods, correspond most nearly to the same desirable composition, but require an admixture of vegetable foods to insure their proper action in the human system. The meats are always defective in essential elements of food, and can never be safely used alone by man. The carnivora, devouring the whole body of their prey, and especially fond of the blood, which contains all its elements in solution, are able thus to live upon animal food.

Working animals are always herbivorous or graminivorous, and, as in the case of man, should have their best dietary carefully determined to insure their efficient action as prime movers, and maximum economy of transformation of the potential energy of their foods into mechanical power. When doing no work an herbivorous diet is probably best; but when working the grains, and when hard worked "cut feed" and coarse meals, mixed with a moderate amount of water and given warm, are best. Cold water should be avoided with meals, and when the creature is warm from exertion especially; but oat-meal water can be safely taken in any quantity by man or beast.

22. The Uses of Foods in the body are thus stated by Professor Atwater*:

Food furnishes:

(1) The material of which the body is made.

(2) The material to repair the wastes of the body, and to protect its tissues from being unduly consumed.

Food is consumed as fuel in the body to:

(3) Produce heat to keep it warm.

---

* *Century Magazine*, July 1887, p. 370.

(4) Produce muscular and intellectual energy for the work it has to do.

The body is built up and its wastes are repaired by the nutrients. The nutrients also serve as fuel to warm the body and supply it with strength.

The protein of food	*forms* the nitrogenous basis of blood, muscle, sinew, bone, skin, etc. *is* changed into fats and carbohydrates. *is* consumed for fuel.
The fats of food	*are* stored in the body as fat. *are* consumed for fuel.
The carbohydrates of food	*are* changed into fat. *are* consumed for fuel.
The mineral matters of food	*are* transformed into the mineral matters of bone and other tissue. *are* used in various other ways.

A growing child or young animal requires much muscle and nerve-making material, and the proportions of the several elements in the food are more nearly those of the body itself than in the case of the adult. The adult, when doing little work, requires little food, and that mainly of the kinds which are required to supply heat and to compensate the slight wastes of tissue then occurring; while the working system, and particularly if hard worked, demands considerable quantities of combustible, heat-producing food. Similar differences of dietary are required, as the climate compels the development of more or less of caloric to preserve the temperature of the body, which at above 104° Fahr., or a little below 98°, fails to meet the requirements of life.

According to Dr. Letheby, the working-power of the human body may be taken as follows*:

---

* Letheby on Food, p. 96.

	Foot-pounds.
External work or actual labor..	1,011,670
Work of circulation (75 beats a minute)....	500,040
Work of respiration (15 a minute)..........	98,496
Total ascertainable work per day......	1,610,206

The ascertainable external and internal work of the food we eat is only one sixth of its actual energy, according to Letheby; but it is not impossible that the unascertained work of the vascular system and other parts may account for the full amount, nearly.

According to Dr. Frankland, this power is supplied by food in the following proportions *:

ENERGY-VALUES OF FOODS.

Name of Food.	Per Cent of Water in Material.	Pounds of Water Raised 1° F.		Pounds Lifted 1 Foot High.	
		When Burnt in Oxygen.	When Oxidized in the Body.	When Burnt in Oxygen.	When Oxidized in the Body.
Butter.............	15	18.68	18.68	14.421	14.421
Cheese.............	24	11.95	11.20	9.225	8.649
Oatmeal....	15	10.30	10.10	7.952	7.800
Wheat flour........	15	10.12	9.87	7.813	7.623
Peameal............	15	10.12	9.57	7.813	7.487
Ground rice	13	9.80	9.52	7.566	7.454
Yolk of egg.........	47	8.82	8.50	6.809	6.559
Lump sugar........	19	8.61	8.61	6.649	6.649
Entire egg (boiled)..	62	6.13	5.86	4.732	4.526
Bread..............	44	5.74	5.52	4.431	4.263
Ham...............	54	5.09	4.30	3.929	3.321
Mackerel....... ...	71	4.60	4.14	3.551	3.200
Lean beef..........	71	3.38	3.01	2.609	2.324
Lean veal..........	71	3.38	3.01	2.609	2.324
Potatoes...........	73	2.60	2.56	2.007	1.987
Milk............. .	87	1.70	1.64	1.312	1.246
Carrots............	86	1.36	1.33	1.050	1.031
Cabbage...........	89	1.12	1.08	.864	.834

* Frankland on Food of Man, 1887, p. 68.

23. Dietaries.—Dr. Pavy gives the following as the quantities of the specified foods required to support human life*:

Nitrogen	300 grains.	
Carbon	4800 "	
	Carbon.	Nitrogen.
14,000 grains (2 lbs.) of bread contain	4200	140
5,500 " (about ¾ lb.) of meat contain	605	165
Total (2¾ lbs.)	4805	305
Six pounds meat	4800 grains carbon.	1309 " nitrogen.
Four pounds bread	9000 grains carbon.	300 " nitrogen.

The estimates of Moleschott for weight of foods in a dry state, for the average individual, are as follow: †

Dry Food.	In Oz. Avoir.	In Grains.	In Grammes.
Albuminous matter	4.587	2006	130
Fatty matter	2.964	1296	84
Carbohydrates	14.250	6234	404
Salts	1.058	462	30
Total	22.859	9998	648

Reckoning ordinary food to contain 50% of water, then, these 23 ounces will correspond to 46 ounces solid food in the condition eaten —additional to this, 60 to 80 ounces of water is taken in some form. The dynamic or force-producing value of this daily standard diet amounts to about 4000 foot-tons.

The relative values of the common articles of diet are given by Scammell as follows ‡:

* Treatise on Food, p. 473.

† Ibid., p. 452. Also Mott's Chart (N. Y., J. Wiley & Sons, 1889).

‡ Mott's Chemist's Manual, p. 575.

THE RELATIVE VALUES OF FOODS.

Articles.	As Material for the Muscles.	As Heat-givers.	As Food for the Brain and Nervous System.	Water.	Waste.
Wheat	14.6	66.4	1.6	14.0	3.4
Barley	12.8	52.1	4.2	14.0	16.9
Oats	17.0	50.8	3.0	13.6	16.9
Northern corn	12.3	67.5	1.1	14.0	5.1
Southern "	34.6	39.2	4.1	14.0	8.1
Buckwheat	8.6	53.0	1.8	14.2	22.4
Rye	6.5	75.2	0.5	13.5	4.3
Beans	24.0	40.0	3 5	14.8	17.7
Peas	23.4	41.0	2.5	14.1	19.0
Rice	5.1	82.0	0.5	9.0	3.4
Potatoes	1.4	15.8	0.9	74.8	7.1
Parsnips	2.1	14.5	1.0	79.4	3.0
Turnips	1.2	4.0	0.5	90.4	3.9
Cabbage	1.2	6.2	0.8	91.3	0.5
Milk	5.0	8.0	1.0	86.0	....
Veal	17.7	14.3	2.3	65.7	....
Beef	19.0	14.0	2.0	65.0	....
Lamb	19.6	14.3	2.2	63.9	...
Mutton	21.0	14.0	2.0	63.0	....
Pork	17.5	16.0	2.2	64.3	....
Chicken	21.6	1.9	2.8	73.7	....
Codfish	16.5	1.0	2.5	80.0	....
Trout	16.9	0.8	4.3	78.0	....
Salmon	20.0	Some fat	6 or 7	74.0	....
Oysters	12.6	....	0.2	87.2	....
Eggs (white of)	13.0	....	2.8	84.2	....
" (yolk of)	16.9	29.8	2.0	51.3	....
Butter	....	100.0	....	....	....
Bacon	8.4	62.5	0.5	28.6	....
Cheese	30.8	28.0	4.7	36.5	....
Chocolate	8.8	88.0	1.8	....	1.4
Cream	3.5	4.5	....	92.0	....
Ham	35.0	32.0	4.4	28.6	....
Lard	....	100.0	....	....	....
Onions	0.5	5.2	0.5	93.8	....
Barley	4.7	78.0	0.2	9.5	7.6

The study of these figures permits the construction of a proper dietary for any case in which stated rations are required or desirable. Professor Atwater gives the following*:

* *Century Magazine*, 1858, p. 258.

STANDARDS FOR DAILY DIETARIES.*

WEIGHTS OF NUTRIENTS AND CALORIES OF ENERGY (HEAT UNITS) IN NUTRIENTS REQUIRED IN FOOD PER DAY.

	Nutrients.				Potential Energy.
	Protein.	Fats.	Carbohydrates.	Total.	
	Grms.	Grms.	Grms.	Grms.	Calories.
1. Children to 1½ years..........	28 (20–36)	37 (30–45)	75 (60–90)	140	767
2. Children 2 to 6 years.	55 (36–70)	40 (35–48)	200 (100–250)	295	1418
3. Children 6 to 15 years........	75 (70–80)	43 (37–50)	325 (250–400)	443	2041
4. Aged woman..................	80	50	260	390	1859
5. Aged man..................	100	68	350	518	2477
6. Woman at moderate work (Voit)..	92	44	400	536	2426
7. Man at moderate work (Voit).	118	56	500	674	3055
8. Man at hard work (Voit).......	145	100	450	695	3370
9. Man with moderate exercise Playfair)...	119	51	531	701	3139
10. Active labor (Playfair).........	156	71	568	795	3629
11. Hard labor (Playfair)....... ...	185	71	568	824	3748
12. Woman with light exercise (Writer)...........	80	80	300	460	2300
13. Man with light exercise (Writer)...........	100	100	360	560	2820
14. Man at moderate work (Writer)..................	125	125	450	700	3520
15. Man at hard work (Writer)....	150	150	500	800	4060

DIETARIES FOR MAN DOING MODERATE MUSCULAR WORK.

	Nutrients.			Potential Energy.
	Protein.	Fats.	Carbohydrates.	
Playfair...........	119 grms.	51 grms.	530 grms.	3135 calories
Moleschott.... ...	130 "	40 "	550 "	3160 "
Wolff.............	120 "	35 "	540 "	3032 "
Voit..............	118 "	56 "	500 "	3055 "

Mr. Edward Atkinson has given a number of dietaries, each having the requisite proportion of proteids,

* Nos. 1, 3, 4, and 5 are as proposed by Voit and his followers of the Munich School; No. 2 by Atwater. One ounce = 28⅓ grammes, nearly.

starch, and fat for thorough nutrition with minimum consumption of food and at minimum cost. Of these the following is an example of a dietary which would serve where low wages or other conditions compel the adoption of most economical rations:

LOW-COST DIETARY.*

Article.	Pounds.	Proteid.	Fat.	Carbo-hydrate.	Calories.	Cost at Boston prices 1891.
Flour........	22	2.64	.44	15.18	36,520	$0.55
Grain........	12	1.68	.84	7.60	19,800	.48
Butter........	2	.02	1.73		7,230	.56
Suet..........	2		1.78		7,200	.12
Sugar..........	2			1.93	3,600	.10
Potatoes......	10	.20		2.10	4,300	.25
Beets, Carrots, Onions, Squash, Cabbage, Parsnips ..	7	.13	.03	.50	1,120	.25
For 30 days...	57	4.67	4.82	27.31	79,770	$2.31
For 1 day.....	1.90	.155	.160	.910	2,659	.077

VARIABLES IN TABLE SHOWING METHOD OF ANALYSIS.

Article.	Pounds.	Proteid.	Fat.	Carbo-hydrate.	Calories.	Cost.
Beef, neck or shin.......	12 (includ'g waste)	2.00	.40		5,200	.72
Mutton, neck.	5	.62	.34		2,476	.30
Bacon........	4	.40	2.80		11,840	.48
Beef-liver....	2	.40	.10		1,120	.12
Veal.........	1	.19	.03		460	.08
Salt Pork.....	1	.03	.78		3,160	.08
For 30 days..	25	3.64	4.45		24,256	1.78
Total....	82	8.31	9.27	27.31	104,026	$4.09
For 1 day....	2.73	.277	.309	.910	3,467.5	.136

The succeeding dietary is one which is considered an economical and satisfactory scheme for families of

* The prices on which these computations are made were the retail prices in Boston, Mass., U. S. A., in the first six months of the year 1891.

small income. In both cases the first list will sustain life, and the second comprises the usually added but unessential articles. In acting as commissary the engineer should endeavor always to provide the equivalent of the first dietary, and, where practicable, the second.

Articles.						Calories.
22 pounds	Flour,	at	$0.02½	$0.55		
3 "	Oatmeal,	at	.04	.12		
3 "	Cornmeal,	at	.03	.09		
6 "	Hominy,	at	.04½	.27		
2 "	Butter,	at	.28	.56		
2 "	Suet,	at	.06	.12		
10 "	Potatoes,	at	.02½	.25		
3 "	Cabbages,	at	.03	.09		
2 "	Carrots,	at	.02½	.05		
2 "	Onions,	at	.05½	.11		
2 "	Sugar,	at	.05	.10		
—— 57					—$2.31	79,770
Variables.						
6 pounds	shin of Beef,	at	$0.06	$0.36		
2 "	round of Beef,	at	.18	.36		
6 "	neck of Mutton,	at	.06	.36		
2 "	Eggs,	at	.18 doz.	.27		
1 "	Cheese,	at	.16	.16		
30 "	Skimmed Milk,	at	.02	.60		
1 "	White Beans,	at	.07	.07		
1 "	Pease,	at	.07	.07		
4 "	Halibut, nape,	at	.05	.20		
2 "	Haddock,	at	.08	.16		
3 "	Salt Cod,	at	.08	.24		
1 "	Oleomargarine,	at	.16	.16		
2 "	Macaroni,	at	.15	.30		
1 "	Oatmeal,	at	.04	.04		
2 "	Cornmeal,	at	.03	.06		
1 "	Rice,	at	.06	.06		
1 "	Hominy,	at	.04	.04		
—— 66					—$3.51	41,051
123 pounds, total for 30 days,					$5.82	120,821
4.1 " " " 1 day,					.194	4,027

Cost per week, $1.35.

24. The "Mechanism of Transmission" of the power of the animal is the vehicle or other apparatus through which the power is exerted in the moving of the load. In some cases the load is directly applied, as where pack-animals are employed; in others a wagon is used; in still other cases the pull on a rope is made effective in raising weights. A strong man can walk an average of about 3½ miles an hour 10 hours a day, unloaded; under 80 pounds he can walk at half this speed seven or eight hours a day; and he may lift at long intervals 180 to 200 pounds. The work of horizontal transport may be approximately computed by taking it at 0.08 the product of weight carried into distance moved over. Thus measured, we find from the above statement that a man should do about 2,000,000 foot-pounds of work per day, his weight being included in the amount taken as load. By the use of a wagon, or its equivalent, the weights that may be transported are increased, often, ten times or more. Training may double the efficiency of a workman in manual employments and enormously increase it in cases of skill coming of long practice. The differences between reputably first-class workmen may amount to 15 or 20 per cent.

The pull of the average draught-animal is usually not far from one fifth its weight. Gerstner gives us the following*:

	Weight. Lbs.	Av. Pull. Lbs.	*V* ft. per Sec. Av.	Work per Sec.	Work per 8-hr. Day.
Man....	150	30	2.5	75	2,160,000
Horse...	600	120	4.0	480	13,824,000
Ox.....	600	120	2.5	300	8,640,000
Mule....	500	100	3.5	350	10,080,000
Ass.....	360	72	2.5	180	5,184,000

* Mechanik, vol. i.

25. **Equations** connecting the time, effort, and work of animals have been proposed, all of which are only approximate, at best; since the conditions of each case are certain to differ more or less from the mean, and are always difficult to evaluate. Rankine follows Maschek, who gives the expression

$$\frac{R}{R_1} + \frac{V}{V_1} + \frac{T}{T_1} = 3;$$

in which R_1, V_1, T_1, are respectively one third, each, of the maximum load, maximum speed, and maximum time in the day's work. Thus a maximum day's work is obtained under the load $R = R_1$, at the speed $V = V_1$, and $T = T_1$, working eight hours per day. Any departure from this adjustment is presumed to give sensible loss of result. Bouguer proposes and Gerstner endorses the following, R_1 and V_1 being maximum loads and speeds:

$$R = \left(1 - \frac{V}{V_1}\right)R_1.$$

Gerstner, taking R_1 and V_1 at their mean values, as per table, would write the equations thus:

$$R = \left(2 - \frac{V}{V_1}\right)R_1; \qquad V = \left(2 - \frac{R}{R_1}\right)V_1.$$

For small variations from the times, loads, and speeds of best effect, the total effect may be taken as varying with those variations.

In ascending inclines, the work may be taken as approximately increasing with the inclination and at a rate proportional to the ratio $1 + (\alpha \div 11.5°)$; since

the work performed in horizontal carriage of burdens is nearly equivalent to raising the total weight one foot in five, for which we have $\sin^{-1}\frac{1}{5} = 11.5°$. The art of securing best results in the use of animals drawing loads in vehicles of various sorts is that of so proportioning load, line of pull, weight of vehicle, and speed of travel as to permit the animal to take its natural gait and best total effort under load, this effort being measured at the traces. Obviously, the lighter the wagon or cart it is found practicable to employ for the proposed load the better. Also, the larger the loads transported in one vehicle the better, as a rule; and thus, in all large operations, heavy loads in comparatively light carriages, and drawn by numbers of animals, give most economical results. As inclines decrease the useful work in rapid proportion with their rise, the production of level and smooth roads is an essential to economy. This is illustrated in the case of railways, where enormous sums are expended to insure straight, level, and smooth tracks. For men the treadmill, and for animals well-constructed "horse-powers," embodying the same principles of construction, give highest efficiency as measured by the work performed per day, in foot-pounds or kilogrammetres. Walking up a moderate incline carrying only the weight of the body is the most casy and natural of all methods of employing its power. This system is capable, however, of but very limited application in ordinary industrial work. It is oftenest seen in use in threshing-machines and other agricultural apparatus.

26. In Selection and Care in the employment of men and animals, the engineer is compelled to regard them as machines, to be selected with careful reference

to the exact requirements of the work proposed to be done, to be handled in such manner as to give him maximum returns for his expenditures, and to be made to produce large commercial results throughout the period of their use. Fortunately, a wise regard of these principles results in giving the man or the animal highest health, in insuring him against overwork, and in encouraging high spirits by the supply of good food, permitting ample allowance for sleep and rest, and prolonging the period of useful life. In exceptional cases the animal machine must be exposed to deleterious influences, overstrain, or liability to serious accident; but these cases can usually be made extremely rare by intelligent engineering, and, in the case of man at least, the individual so exposed receives what is thought by him satisfactory compensation for the risks so taken.

In the selection of the man or animal for a specified work, the wise and experienced engineer, or his contractor, looks for light, active, spirited creatures for light work, heavy and powerful, though slow, animals for heavy work, and can usually find just that combination of qualities of body, intelligence, and spirit which his experience teaches him are best for the specified purpose. The racehorse, the roadster, the hackney, and the draught-animal all have their special parts to perform. Neither can satisfactorily do the work of the other; and the same is true of man, whether performing purely manual labor, working at a trade, or taxing his mind in the direction of an industrial army or otherwise. For every sort of task there is to be found a kind of man specially and peculiarly adapted to its successful accomplishment. Not only

individuals, but families, tribes, and even races, adapt themselves, through natural constitution and peculiar characteristics of body and mind, to special kinds of work. Among the best species, races, tribes, or families, individuals may always be found especially well fitted to perform a specified work; and among such individuals, the age, state of health, conditions of environment, may produce serious differences at different times. All such variations are noted by the engineer and serve as the basis of his judgment in apportioning work, in assigning duties, and in determining compensation.

The work once assigned, the person in charge should be expected not only to see that the conditions of best effect are adhered to, strictly and continuously, but to arrange the times and methods of serving meals, the character, amount, and method of preparation of the dietary with a view to insuring the best possible conversion of its potential energy into work and at minimum cost consistent with highest results. Even satisfaction with the bill-of-fare, by promoting appetite and digestion, is an element of success, with animals as well as with men. Periods of rest should be so arranged that the food may be taken neither when fatigue nor immediately succeeding labor may interfere with its digestion. Two meals, even one hearty and well-digested meal per day is sometimes found, for this reason, better, on the whole, than a larger number resulting in impaired digestion and defective nutrition. In hot climates, particularly, natives are observed often to be well satisfied with a single meal, taken after a hard day's work; the precaution being observed to secure an hour of complete rest before

taking it. Hard-worked stage-horses, fed an hour before going upon the road in the morning with a warm mixture of cut hay and corn-meal, moderately wet, and fed again after their rest on coming in at night, have been found to do the season's work better than when given a third meal at noon. The meal should, in all cases, consist of nutritious food of proper composition, and in ample quantity to satisfy the appetite, without permitting excess.

No less essential in securing the most that can be obtained from the working man or animal is the provision of suitable clothing and housing. Weather-tight, warm, thoroughly comfortable, and yet well-ventilated stables are essential to highest economy in the employment of animals; and the same care, precisely, is demanded in providing for men, with the additional requirement that everything within reason that shall conduce to content and cheerfulness, high spirits, ambition, and an inclination to do their best work should be conscientiously provided.

III.

FINAL DEDUCTIONS.*

27. **Our Progress,** whether in the direction of industrial improvement or of intellectual growth, depend, the first mainly, the second largely, upon the extent and the success of man's utilization of the four great natural forces, or "energies," as the man of science calls them: heat, light, electricity, mechanical or dynamic power. Civilization is based upon their application to the purposes of humanity in the world of matter; intellectual and even moral progress is advanced by that steady march of improvement which, in modern times especially, has so constantly promoted the material welfare of the world, and has thus given leisure for that employment of the mind in higher work which is the essential prerequisite to either intellectual or moral elevation.

The greatest of all our problems to-day is thus that of making this utilization of the forces of nature more general, more efficient, and more fruitful. Could the engineer, to whom all this work is intrusted, find a way of producing steam-power at a fraction its present cost; could he transform heat energy directly and without waste into dynamic; could he find a method of evolution of light without that enormous loss now

* From *The Forum*, Sept. 1892: "The Great Problems of Science," by R. H. Thurston.

inevitable in the form of accompanying heat; could he directly produce electricity, without other and lost energy, from the combustion of fuel—could he do these things to-day, the growth of all that is desirable to mankind and the advancement of all the interests and powers of the race would be inconceivably accelerated. Moral sentiments, logical power, inventive genius, capacity for accomplishing all the grander tasks of civilization, develop together. All gain and retain existence through the mysterious power, possessed by all, of transforming and utilizing those original natural energies coming to us all alike from the central sun, and to the central sun from initial chaos and a diffused universe. Every motion and every power of each and all is due to conversion of these primary energies for a specific purpose and in a specific manner.

The engineer, to whom is confided this duty of utilizing all the forces of nature for the benefit of his fellows, has, however, now apparently reached a point beyond which he can see but little opportunity for further improvement, except by slow and toilsome and continually limited progress. He seems to have come very nearly to the limit of his advance in the directions which have, up to the moment, been so fruitful of result. His steam-engine is doing nearly the best that can be done, so far as he can see, in the conversion of heat into power; light is produced through the steam-engine and the dynamo-electric machine about as efficiently as he can hope to obtain it by known methods; heat is obtainable for his thousand purposes, economically at least, only by the combustion of his rapidly disappearing stores of fuel laid by in the past millenniums for his use during a brief life on the globe,

and without visible substitute when they shall have been exhausted; and civilization, the life of the race, dependent upon our coal-beds, is only assured of ultimate and, on the geologist's scale of time, early extinction; unless, indeed, again consulting nature and studying the lessons of life, as we have so often profitably done before, we can learn of new ways of availing ourselves of existing forms of energy in nature, or of enormously improving our methods and reducing those wastes which are now so frightful, as judged from the standpoint of both the engineer and the man of science. Whether we can expect or even hope to accomplish the first of these tasks is extremely doubtful, not to say absolutely improbable; that we may possibly succeed in the second may be less unlikely. In any case, our only recourse is the same method which has brought us all that we now possess: scientific research and the study of nature's own methods.

28. **What we are to Seek** is, first, a method of producing, directly or by modification of other ether-vibrations, just that sort of ether-wave which we require, in the form of heat, light, or electricity, of exactly defined rate and amplitude of vibration; secondly, the complete transformation of either or all forms into mechanical power, into "dynamic" energy. It is easy to say and usually is safe to assert that what has been done may be again done; what is accomplished to-day in nature may be, in a similar manner or by parallel methods, performed by man. Nature accomplishes many of the tasks that man is about attempting, and has been holding up to him the solution of his problems throughout the ages. It is

for him to solve her riddles and thus to obtain power at a fraction of its present cost; prolong the life of the race indefinitely; secure light, isolated from heat, and in many times the quantity for a given amount of labor now expended; and produce electricity without loss and directly, instead of, as at present, through the intervention of heat-engines with their now enormous wastes. Human progress depends upon the ability of mankind to do more work, and to accomplish greater tasks, to supply the necessaries of life with less expenditure of time and strength, thus to secure leisure for the production of the comforts and the luxuries that give modern society its characteristics, and to insure that leisure for thought, invention, intellectual development of every kind, which still more strikingly characterize the highest civilization. In all this, only the application of the forces of nature without waste and the complete subjection of all its energies can give maximum result.

It is now well known that the heat-engines, whether steam, gas, hot air, or ether, only utilize a fraction of the power latent in their fuel, and that this fraction, as a maximum, in even an ideally perfect engine, is measured by the division of the range of temperature through which they expand their "working fluids" by the "absolute" temperature of the fluid as supplied to the engine; that is, a temperature measured from a point about 460°, on the Fahrenheit scale, below the Fahrenheit zero. This fraction, we have learned, is, in the case of the modern steam-engine, usually between one fourth and one half; while the actual performance of our engines falls to one fourth or one half this ideal maximum, in the ordinary and best

engines, respectively.* The engine fully utilizing, ideally, but two and one half pounds of steam and one fourth of a pound of coal per horse-power per hour practically demands six to eight times this amount, even when of the best construction; while the average engine probably utilizes but one pound in ten, and often but one in twenty, wasting from ninety to ninety-five per cent of all the heat from its furnaces. The gas-engine gives higher thermodynamic performance than the steam-engine; but it compensates this advantage by loss, through a "water-jacket," of one-half of all the heat that it should completely transform into useful work.† No method is yet discovered of imitating nature in direct conversion of heat into other forms of energy without waste; and our production of light, in our most recent and most wonderful inventions, involves the same waste by the intermediate use of the heat-engine for primary transformation of heat into mechanical energy, in turn to be converted, with great efficiency, into electricity, thence to be once more transformed, with great waste again, into light. The direct evolution of light, purely, or of electricity alone and without loss, from fuel oxidation, though it is constantly performed by nature, is as yet beyond the power of man. Could these problems of life be solved, power and light would cost us but a small fraction of their cost to-day; and the exhaustion of our coal-beds would be deferred

* "Steam and its Rivals," R. H. Thurston: *Forum*, May 1888, p. 341. Also "Manual of the Steam-engine," vol. i. (New York, J. Wiley & Sons, 1890).

† "Last Days of the Steam-engine," R. H. Thurston: *North American Review*, July 1889.

thousands of years. Were grander problems ever presented or nobler prizes ever offered the man of science than these? Nature solved them in the earliest days of the earth's history; it begins to seem probable that man may find a way to penetrate the secrets and solve the problems of life and vitality. All that he seeks may be evolved from the mysteries and lessons of life.

29. **The Living Body** is a machine in which the "law of Carnot," which asserts the necessity of waste in all thermodynamic processes and in every heat-engine, and which shows that waste to be the greater as the range of temperature worked through by the machine is the more restricted, is evaded; it produces electricity without intermediate conversions and losses; it obtains heat without high-temperature combustion, and even, in some cases, light without any sensible heat. In other words, in the vital system of man and of the lower animals nature shows us the practicability of directly converting any one form of energy into any other, without those losses and unavoidable wastes characteristic of the methods the invention of which has been the pride and the boast of man. Every living creature, man and worm alike, shows him that his great task is but half accomplished; that his grandest inventions are but crudest and remote imitations; that his best work is wasteful and awkward. Every animate creature is a machine of enormously higher efficiency as a dynamic engine than his most elaborate construction as illustrated in the 30,000 horse-power engines of the "Campania" or the "Lucania," or in the most powerful locomotive. Every gymnotus living in the mud of a tropical stream puts to shame man's best effort in the

production of electricity; and the minute insect that flashes across his lawn on a summer evening, or the worm that lights his path in the garden, exhibits a system of illumination incomparably superior to his most perfect electric lights.

Nature in each of these cases converts the energy of chemical union, probably of low-temperature oxidation, into just that form of energy, whether mechanical or of a certain exactly defined and required rate of ether-vibration, that is best suited to the intended purpose, and without waste in other force, utilizing even the used-up tissue of muscle and nerve for the production of the warmth required to retain the marvellous machine at the temperature of best efficiency, whatever the environment, and exhaling the rejected resultant carbonic-acid gas at the same low temperature. Here is nature's challenge to man! Man wastes one fourth of all the heat of his fuel as utilized in his steam-boiler, and often ninety per cent as used in his open fire-places; nature, in the animal system, utilizes substantially all. He produces light by candle, oil-lamp, or electricity, but submits to a loss of from one fifth to more than nine tenths of all his stock of available energy as heat; she, in the glowworm and firefly, produces a lovelier light without waste measurable by our most delicate instruments. He throws aside as loss nine tenths of his potential energy when attempting to develop mechanical power; she is vastly more economical. But in all cases her methods are radically different from his, though they are as yet obscure. Nature converts available forms of energy into precisely those other forms which are needed for her purposes, in exactly the right quantity, and never wastes, as does invariably the

engineer, a large part of the initial stock by the production of energies that she does not want and cannot utilize. She goes directly to her goal. Why should not man? He has but to imitate her processes.

Mysterious as seem these processes and methods, however, and wonderful as seem their results when compared with the crude ways of the engineer and the man of science, we at least know something of them, and are even familiar with many facts relating to them. The facts are these: Every living creature throughout the animal kingdom is a machine which takes into its internal furnace, or whatever it may prove to be, its fuel, its "food," composed of vegetable matter or, like the body receiving it, itself directly derived from vegetation; and by a chemical process in what the chemist calls the "wet way" it consumes this food, the resulting products of this chemical action being such as, dissolved in the blood, may be converted into brain, nerve, muscle, and fat; and by later combustion and transformations at low temperature it may produce heat certainly, electricity probably, often light, and always mechanical power. The composition of this fuel is known to be principally familiar chemical elements mingled with the rarer in minute proportions. The hydrocarbons, water, and a little lime, phosphorus, sulphur, and other minerals, such as iron, constitute the food of all living creatures.

Every process involved is carried on at "blood-heat" in the higher animals, and at much lower temperatures in the "cold-blooded" creatures; and all parts of the system are retained at substantially the same temperature at all times. All heat is thus the result of low-temperature combustion; all light and electricity are

evolved at a constant low point on the scale, and these energies are converted into new forms, or into dynamic energy, and applied to the performance of work without variation of that temperature. That heat *is* produced is a matter of constant experience and observation, and we throw off more as we work harder, whether with mind or body, and as we move more rapidly. That this heat, so far as converted into other energies by the body, must be so converted at a sensibly constant temperature is obvious from the fact that the change goes on in a mass of circulating fluids; that this proves that the conversion is not thermodynamic, but is due to some entirely different and unknown method, is equally evident to the engineer, who understands that only so could the "law of Carnot" be evaded. That this action is possibly electrodynamic is indicated by the fact that electric currents traverse the system, and that we may at any moment compel the muscles to do work by the application of a current from an external source.

30. **Of the Methods of Production of Energies** in the body, we know as yet absolutely nothing; but we do know that electricity may be produced in large quantity, and at "high pressure," as the electrician says, as illustrated by the torpedo and the gymnotus or electric eel; and the anatomist knows the mechanical structure of the organs from which it is evolved, though he is ignorant of the processes therein conducted. We also know that the best currents for electrodynamic operations are those of low intensity, such as are easiest of control and insulation in the body. By analogy with the other methods of transformation, we may presume that the source of this

vital fluid in the animal is low-temperature combustion or other chemical action, and that a system of direct conversion is there in operation.

Scientific men are somewhat more familiar with the case of the firefly, curiously enough; that is to say, the production of light without heat, as well as the transformation of energies resulting in the economical production of heat and power in the animal system. It has long been known that certain chemical compounds, notably fats containing sulphur and phosphorus, may be burned at exceedingly low temperatures, with an evolution of a mild light almost or quite entirely free from heat. Some such compounds are found in nature, and the chemist has artificially produced others. He finds that he may at will produce, in some cases, slow and cold light-production or rapid and heat-producing oxidation. Numerous experiments upon the firefly and the glowworm indicate that theirs is a light thus obtained. This so-called "phosphorescence" is seen in many insects, worms, fishes, and mollusks, and even in vegetable and mineral matter. For a century this investigation has been in progress, and it is well established that the low-temperature combustion of a peculiar substance, given form in the body of the firefly, for instance, by peculiar organs specially constituted for that purpose, results in the production of light without heat. This has been most recently and most conclusively proved by Messrs. Langley and Very, who show by actual measurement with the Langley "bolometer," an instrument capable of measuring even the heat received from the moon, that "insect light" is accompanied by approximately one four-hundredth part of the heat which is ordinarily

associated with the radiation of flame of the luminous quality of those familiar to all of us. Thus "nature produces this cheapest light at about one four-hundredth part of the cost of the energy which is expended in the candle-flame and at but an insignificant fraction of the electric light or the most economic light which has yet been devised." Many deep-sea fishes and numberless animalcules exhibit a solution of this problem.

31. **The Advantage** to be hoped for from the substitution of the economical ways of nature for the wasteful ways of man may be imagined from the following facts: Experiments by Mr. Merritt, in the Cornell University laboratories, have shown the wastes of the incandescent electric lamp to be from 93½ to 99½ per cent, according to intensity of current; while Mr. Nakano's tests, in the same place, of the arc lamp give a waste of 95 to 84 per cent. The insect wastes almost nothing. But even now the electric light has ten or fifteen times the efficiency of the oil-lamp, and is still better as compared with the candle. Professor Langley found the common gas-burner to waste 99 per cent of the developed energy of combustion. His fireflies were more efficient in the proportion of one to thousands. The six millions of tons of coal supposed to be concealed in the earth, at our present rate of consumption, if employed for power-production, would supply about fifteen thousand millions of horse-power for twelve thousand years; but could we discover and employ nature's methods and gain in such proportion as is indicated above, we might feel sure that all the wants of the race would be supplied as long as the earth should continue the possible abode of man. Years ago it was remarked in an inaugural address as presi-

dent of the "American Society of Mechanical Engineers"*:

"I have sometimes said that the world is waiting for the appearance of three great inventors, yet unknown, for whom it has in store honors and emoluments far exceeding all ever yet accorded to any one of their predecessors. The first is the man who is to show how, by the consumption of coal, we may directly produce electricity, and thus, perhaps, evade that now inevitable and enormous loss that comes of the utilization of energy in all heat-engines driven by substances of variable volume. Our electrical engineers have this great step still to take, and are apparently not likely soon to gain the prize that will reward some genius yet to be born. The second of these greatest of inventors is he who will teach us the source of the beautiful soft-beaming light of the firefly and the glowworm, and will show us how to produce this singular illuminant and to apply it with success practically and commercially. This wonderful light, free from heat and from consequent loss of energy, is nature's substitute for the crude and extravagantly wasteful lights of which we have, through so many years, been foolishly boasting. The dynamo-electrical engineer has nearly solved this problem. Let us hope that it may be soon fully solved, and by one of those among our own colleagues who are now so earnestly working in this field, and that we may all live to see him steal the glowworm's light and to see the approaching days of Vril predicted so long ago by Lord Lytton. The third great genius is the man who is to fulfil Erasmus Darwin's prophecy closing the stanza:

* Transactions "A. S. M. E.," November 1881, R. H. T.

" 'Soon shall thy arm, unconquered steam, afar
Drag the slow barge or drive the rapid car,
Or on wide-waving wings expanded bear
The flying chariot through the fields of air' "

And even this latest of the mechanic's triumphs, already known to present far less difficulty than was formerly supposed, will attain highest success only when nature's methods of energy-transformation are discovered and adopted.

Should the day ever come when transformations of energy shall be made in nature's order, and when thermo-electric changes shall be a primary step toward electrodynamic application to purposes now universally attained only by the unsatisfactory processes of thermodynamics as illustrated in our wasteful heat-engines, the engineer, following in his work the practice of nature, which has been so successful throughout the life of the animal kingdom, will find it easy to drive his ship across the ocean in three days; will readily concentrate in the space now occupied by the engines of the "Majestic" a quarter of a million horse-power; will transfer the 3,000,000 horse-power of Niagara to New York, Boston, Philadelphia, to be distributed to the mills, shops, houses, for every possible use, furnishing heat, light, and power wherever needed; and may possibly do quite as much for the benefit of mankind by breaking up the modern factory system and distributing labor in comfortable quarters as by this reduction of costs of products to the consumer. One of the many difficulties in the way of successful navigation of the air is known to be that of securing some propelling instrument that shall not weigh more than about ten pounds to the horse-power. Could we evade Carnot's

law by complete energy-transformation, we could to-day build engines of over 400 horse-power to the ton weight, and that obstacle would be out of our way. Could we completely transform heat or mechanical power into light, a resulting advantage would also be the reduction of the whole system of light-producing machinery in weight and bulk in corresponding degree. These gains would be observed in innumerable directions.

32. **Costs.**—On the other hand, nature in all her transformations makes use of chemical processes and organic and complex compounds that may prove to be too costly as substitutes for the fuels, though the latter are subject to present wastes; and thus the question of dollars and cents, always controlling, comes in to confuse the wisest of scientific men. However that may be, these problems must always afford instructive lessons to the student of the mysteries of nature; and the bare possibility that by following her methods he may find ways of so enormously benefiting his fellow-man and of adding so greatly to the comfort, the pleasure, the safety, and the opportunities of the race, must be quite sufficient to stimulate every young aspirant for fame and every lover of research to strive to achieve some one or all of these solutions of the grandest scientific problems that remain unsolved. It seems more than probable that it is to the mysteries and lessons of life that the chemist, the physicist, the engineer, must turn in seeking the key that shall unlock the still unrevealed treasures of coming centuries. These constitute nature's challenge to the engineer.